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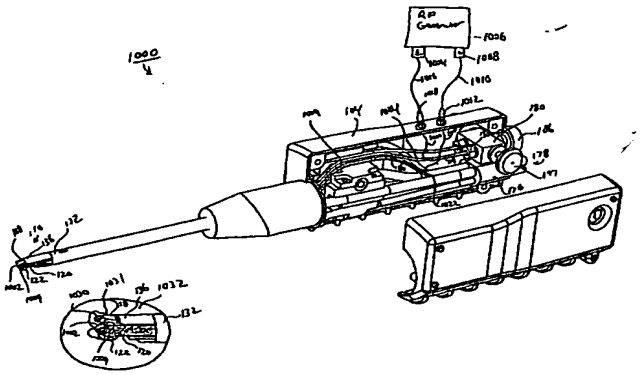
(54) Title: SURGICAL INSTRUMENTS WITH INTEGRATED ELECTROCAUTERY



(57) Abstract: The present invention provides a series of devices for performing surgical procedures utilizing electrodes for performing electrocautery on a tissue of the body of a patient. The invention includes, in one aspect, a series of devices comprising surgical instruments providing at least one electrode for performing electrocautery, and, in another aspect, provides a method for cutting and cauterizing tissue with a surgical instrument. In yet another aspect, the invention involves a method for detecting the location of a bleeding vessel in a liquid-filled, visually monitored surgical field of a patient and for electrocauterizing the vessel to stop the bleeding before visualization of the surgical field is compromised. Preferred surgical instruments according to the invention also include operable components for forming a liquid cutting jet for cutting or ablating tissue of a patient and/or for providing a rotating, tissue contacting component for cutting, grinding, ablating, etc. tissue during a surgical procedure. Some surgical instruments, according to the invention, include one or more liquid conducting lumen therein for transporting and/or removing a liquid from a surgical operating field, which lumen, in some cases, are selectively coated with a layer of an electrically insulating material so that certain, selected, uncoated regions of an external surface of the lumen can act as an electrocautery electrode of the instrument.

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SURGICAL INSTRUMENTS WITH INTEGRATED ELECTROCAUTERY

FIELD OF THE INVENTION

The invention relates to surgical instruments for performing a surgical procedure on a patient that include at least one integrated electrocautery electrode, and to methods for using the instruments in surgical procedures.

BACKGROUND OF THE INVENTION

Traditionally, many surgical procedures have been performed on patients using open surgical methods that utilize relatively large incisions to expose a surgical field. Many traditional methods have also typically utilized surgical tools such as scalpels, scrapers, blunt dissectors, lasers, electrosurgical devices, etc., which can have poor tissue differentiating capability and which can sometimes cause inadvertent damage to tissue surrounding a surgical treatment site unless carefully utilized. Open surgery with such prior art surgical instruments often involves extensive trauma to the patient, with associated problems of long recovery periods and potential complications.

There has been a trend in recent years to perform many surgical procedures using less invasive techniques by accessing surgical sites via small holes through the skin or through body orifices. These techniques are known as "minimally invasive surgery." Minimally invasive surgical techniques commonly employed include endoscopic, laparoscopic, and arthroscopic surgical procedures. Minimally invasive surgical procedures are commonly preferred to open surgical procedures for many applications because the minimally invasive procedures induce less trauma to the patient during surgery and involve, in many cases, fewer potential complications and reduced recovery time.

A variety of surgical instruments have been developed and utilized both for minimally invasive surgical procedures and for more traditional open surgical procedures. Frequently used instruments include blade and scalpel-type instruments, motorized rotary cutting and/or grinding instruments, laser instruments, liquid jet cutting instruments, and electrosurgical instruments. Typically, prior art instruments suffer from a variety of disadvantages. For example, typical prior art surgical instruments, especially those utilized for minimally invasive surgical procedures, have distal ends including a single component for performing a particular surgical function. Surgical instruments having distal ends including, for example, a rotating cutting or grinding head, a tissue-ablating laser, a liquid cutting jet, or an electrosurgical cutting jet are known in the art. Many of these prior art instruments suffer

that surgical instruments be coupled to a source of highly pressurized gas during operation of the instruments, which can be inconvenient, expensive, or undesirable.

U.S. Patent No. 5,803,733 to Trott et al. describes a pneumatically powered surgical handpiece in which the pressurized fluid inlet is axially directed relative to the handpiece body. The handpiece includes a reaction-type turbine that is rotated by fluid flowing within a closed conduit. The handpiece utilizes a cantilevered turbine rotor, wherein the output shaft of the handpiece and the turbine rotor rotate about axes which are co-linear.

Surgical instruments utilizing liquid-driven turbine rotors are also known. U.S. Patent No. 4,631,052 to Kensey describes an elongated, flexible recanalization catheter that includes a working head which is adapted to be rotated by a turbine drive in operation. The turbine drive utilizes a liquid-driven turbine rotor comprising a reaction turbine whose rotational motion is imparted by pressure driven liquid flowing in a closed conduit. The turbine rotor and the rotating working head of the device are directly coupled together so that they rotate at essentially the same speed during operation. In addition, the rotor assembly is disposed at the distal end of the catheter and is essentially completely submerged in liquid during operation.

U.S. Patent No. 4,690,140 to Mecca describes a catheter for use in the removal of deposits lining the interior wall of a blood vessel that includes a rotating cutting device at its distal end. Rotational motion of the rotating cutting device is imparted by flow of a pressure-driven liquid. The cutting surfaces of the rotating cutting device and the turbine rotor comprise a single component rotating at essentially the same speed and about the same rotational axis. As with the '052 patent described above, the rotating cutting element of the '140 patent is disposed at the distal end of the catheter such that the turbine rotor causing rotation of the device is essentially completely submerged in liquid during operation.

Surgical instruments providing electrosurgical cutting or cauterizing electrodes in combination with rotating surgical components or liquid perfusion and/or aspiration capabilities are also known.

U.S. Patent No. 5,527,331 to Kresch describes a tissue resection device for use in an organ inflated with a non-conductive fluid. The distal end of the device can include a perfusion lumen, a rotatable drive tube, and a drive tube aspiration lumen. A cutting tip can be mounted on the distal end of the drive tube. In some configurations, the cutting tip is further configured to act as an electrosurgical resection electrode.

U.S. Patent No. 5,941,876 to Nardella et al. describes an electrosurgical apparatus that includes a rotary, tissue affecting device, such as a rotating blade component, a rotating drill,

SUMMARY OF THE INVENTION

The present invention provides a series of devices for performing surgical procedures utilizing electrodes for performing electrocautery on a tissue of the body of a patient. The invention includes, in one aspect, a series of devices comprising surgical instruments providing at least one electrode for performing electrocautery, and, in another aspect, provides a method for cutting and cauterizing tissue with a surgical instrument. In yet another aspect, the invention involves a method for detecting the location of a bleeding vessel in a liquid-filled, visually monitored surgical field of a patient and for electrocauterizing the vessel to stop the bleeding before visualization of the surgical field is compromised.

In one aspect, the invention provides a series of surgical devices with integrated electrocautery. One device comprises a surgical instrument having a distal end adapted to perform a surgical procedure on a patient and a proximal end controllable by an operator. The instrument includes a pressure lumen having sufficient burst strength to conduct a high pressure liquid towards the distal end of the instrument. The pressure lumen includes at least one nozzle providing a jet opening. The nozzle is shaped to form a liquid cutting jet as a liquid at high pressure flows therethrough. The instrument further includes a rotatable shaft and a surgical component drivable by the shaft and constructed and arranged for contact with tissue in a surgical operating field. The instrument further includes at least one electrocautery electrode.

Another device comprises a surgical instrument having a distal end adapted to perform a surgical procedure on a patient and a proximal end controllable by an operator. The instrument includes a rotatable shaft and a surgical component drivable by the shaft and constructed and arranged for contact with tissue in a surgical operating field. The instrument further includes a liquid jet-driven rotatable rotor drivingly coupled to the rotatable shaft, when the instrument is in operation, such that rotation of the liquid jet-driven rotatable rotor causes a corresponding rotation of the rotatable shaft. The instrument further includes at least one electrocautery electrode.

Yet another device comprises a surgical instrument having a distal end adapted to perform a surgical procedure on a patient and a proximal end adapted to be controllable by an operator. The instrument includes a pressure lumen having sufficient burst strength to conduct a high pressure liquid towards the distal end of the instrument. The pressure lumen includes at least one nozzle providing a jet opening. The nozzle is shaped to form a liquid cutting jet as a liquid at high pressure flows therethrough. The instrument further includes an

bleeding vessel and flowing towards and into the evacuation lumen of the surgical instrument, moving the surgical instrument within the surgical field along the trail of blood towards the bleeding vessel, placing at least one electrode surface of the surgical instrument in proximity to the bleeding vessel, and applying an electrical signal to the electrode to electrocauterize the bleeding vessel to stop bleeding therefrom.

Other advantages, novel features, and objects of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings, which are schematic and which are not intended to be drawn to scale. In the figures, each identical or nearly identical component that is illustrated in various figures is represented by a single numeral. For purposes of clarity, not every component is labeled in every figure, nor is every component of each embodiment of the invention shown where illustration is not necessary to allow those of ordinary skill in the art to understand the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic, perspective illustration of a surgical liquid jet instrument providing a liquid cutting jet and a rotating burr at its distal end, with the body of the instrument disassembled to show the internal components thereof;

FIG. 2A is a schematic, exploded, perspective illustration of a portion of the surgical instrument as in FIG. 1 showing the sheath and collar and components contained therein;

FIG. 2B is a schematic, cross-sectional illustration of the distal end of the surgical instrument as in FIG. 2A showing the distal end of the rotatable shaft and the support element therefor;

FIG. 2C is a schematic, cross-sectional illustration of the rotatable shaft and support element of the instrument as in FIG. 2B;

FIG. 3 is a schematic, perspective illustration of the surgical instrument as in FIG. 1, excluding the body of the instrument, and as viewed from the proximal end of the instrument;

FIG. 4 is a schematic, partially-cutaway, perspective illustration of the surgical instrument as in FIG. 1, wherein the sheath component has been rendered transparent;

FIG. 5A is a schematic, perspective illustration of a portion of a surgical instrument showing an alternative embodiment for providing a distal end including a liquid cutting jet and a rotatable grinding burr;

FIG. 10A is a schematic, perspective illustration of a curved-vein rotor;

FIG. 10B is a schematic illustration of several curved veins of the curved-veined rotor as in FIG. 10A;

FIG. 11A is a schematic illustration of one embodiment of a configuration for providing evacuation for a surgical instrument;

FIG. 11B is a schematic illustration of another embodiment for providing evacuation for a surgical instrument;

FIG. 12 is a schematic, cross-sectional illustration of the liquid flow directing valve of the instrument as in FIG. 1;

FIG. 13 is a schematic, cross-sectional illustration of the pressure-tight sealing component and spacer component of the liquid flow directing valve as in FIG. 12;

FIG. 14A is a schematic illustration of a rotatably deployable surgical liquid jet instrument including integrated electrocautery electrodes;

FIG. 14B is a schematic illustration of a portion of the surgical liquid jet instrument as in FIG. 14A showing more clearly the distal end of the instrument, when in the undeployed configuration;

FIG. 14C is a schematic illustration of a portion of the liquid jet instrument as in FIG. 14A showing more clearly the distal end of the instrument, when in the deployed configuration;

FIG. 14D is a partially-cutaway, schematic illustration of a portion of the surgical liquid jet instrument as in FIG. 14A;

FIG. 14E is a partially-cutaway, schematic illustration of a portion of the surgical liquid jet instrument as in FIG. 14A;

FIG. 14F is a schematic illustration of the actuating element of the surgical liquid jet instrument as in FIG. 14A;

FIG. 15 is a series of schematic illustrations illustrating a method for forming a liquid jet nozzle region;

FIG. 16A is a schematic, perspective illustration of a surgical instrument as in FIG. 1, but including integrated electrocautery electrodes; and

FIG. 16B is a schematic, perspective illustration of a portion of the surgical instrument as in FIG. 16A, showing the configuration of the distal end of the instrument.

liquid cutting jet to cut, drill, bore, perforate, strip, delaminate, liquefy, ablate, shape, form, etc. various tissues, organs, etc. of the body of a patient.

The liquid jet surgical instruments provided by the invention preferably include at least one pressure lumen that has a distal end terminating in at least one nozzle that provides a liquid jet opening, and that has a proximal end that is connectable so as to be in fluid communication with a source of liquid under high pressure, supplied, for example, by a high pressure pump or high pressure liquid dispenser. The liquid jet nozzle is shaped to form a liquid jet as a liquid under high pressure flows through the nozzle as described in greater detail below. The liquid jet, in certain embodiments, is used to create a driving force for rotating a rotatable shaft of the instrument that can extend, in preferred embodiments, from the body of the surgical instrument towards the distal end of the instrument. In some embodiments, the instrument includes a pressure lumen that conducts a high pressure liquid toward the distal end of the instrument and that includes at least one nozzle that creates a liquid cutting jet as a high pressure liquid flows therethrough. The liquid cutting jet, for embodiments wherein the surgical instrument provides a liquid cutting jet at its distal end, can be used to cut, ablate, sculpt, trim, form, debride, etc., various tissues of a patient in surgical procedures.

In some especially preferred embodiments, the surgical instruments provided by the invention include two pressure lumen, one for forming a liquid cutting jet at the distal end of the instrument and the other for forming at least one liquid jet utilized to drive the rotation of a rotatable shaft included in the surgical instrument. In some preferred embodiments, the liquid pressure supplied to the instrument by a high pressure pump or high pressure dispenser can be variably controllable by an operator of the instrument so that the cutting or ablating power of the liquid cutting jet, or the power supplied to rotate the rotatable shaft, is adjustable by the operator. This adjustability of the pressure can allow an operator to create a liquid cutting jet with the instrument that can differentiate between different types of tissue within a surgical operating field and/or can allow an operator to rotate a rotatable shaft of the instrument at varying rotational speeds with varying maximum achievable levels of torque according to the particular needs of the surgical procedure for which the distal end of the rotating shaft is being utilized.

For example, for embodiments including a liquid cutting jet provided at the distal end of the instrument, a lower pressure can be utilized for cutting or ablating a soft tissue, such as fat, from a surface of a harder tissue, such as muscle or bone, where the liquid jet has

surgical cutting or ablating of tissue with a reduced danger of causing unintended collateral damage to tissue lying beyond the target/dissipater in the surgical operating field.

In some embodiments, the target/dissipater can be simply a solid surface capable of dissipating the energy of a liquid cutting jet by transforming the liquid jet into a harmless spray. In more preferred embodiments, however, the target is defined by a jet-receiving opening included in an evacuation lumen that forms part of the surgical instrument. In the preferred embodiments of instruments including an evacuation lumen having a jet-receiving opening, in addition to providing a defined liquid jet length (defined by the predetermined distance between the liquid jet opening and the jet-receiving opening) and preventing unintended damage as discussed above, the evacuation lumen can also be utilized for removing liquid, ablated tissue, and debris from the surgical field. In some embodiments of surgical jet instruments having an evacuation lumen for receiving a liquid cutting jet according to the invention, an external source of suction, for example a vacuum pump or aspirator, can be provided in fluid communication with a proximal end of the evacuation lumen in order to provide the suction driving force required for evacuating material from the surgical field via the jet-receiving opening. In some preferred embodiments, however, the invention provides surgical instruments having an evacuation lumen that is shaped and positionable relative to the jet nozzle forming the liquid cutting jet (as will become apparent to those of ordinary skill in the art from the detailed description below) to enable evacuation of essentially all of the liquid comprising the liquid cutting jet as well as ablated tissue and debris from the surgical site without requiring an external source of suction. In some preferred embodiments, the evacuating force created by the liquid cutting jet being directed into the evacuation lumen is sufficient to evacuate material from the operating site to a drainage reservoir located at the proximal end of the evacuation lumen or an evacuation conduit connected to the proximal end of the evacuation lumen. In such embodiments, the liquid cutting jet and the evacuation lumen together act as an eductor pump, which utilizes the momentum and kinetic energy of the moving fluid of the liquid cutting jet to create an evacuating force capable of driving liquid, ablated material, and debris through the evacuation lumen and away from the surgical site.

As discussed in detail below, the invention teaches that the effectiveness of evacuation of material through the evacuation lumen without the use of an external source of suction (i.e., via eductor pump action) can be improved, in some instances, by designing certain inventive instruments to provide particular geometrical relationships between the

receiving opening. As used herein in the context of describing geometric relationships between longitudinal axes of various components, the term "co-linear" refers to components whose longitudinal axes are superimposed on essentially the same line and space. The term "parallel" when used in the same context refers to longitudinal axes that are not necessarily co-linear, but that are oriented in an essentially identical direction in space. Accordingly, surgical instruments provided according to certain embodiments of the invention enable effective evacuation of material and debris from the surgical site via a liquid cutting jet evacuation lumen, without the need for an external source of vacuum connected in fluid communication with such lumen, for a wide variety of liquid cutting jet angular configurations, including instruments providing liquid cutting jets that are directed axially, transversely, or at any angle between 0 and 180° with respect to a longitudinal axis defining the proximal end or body of the surgical instrument.

For embodiments involving surgical instruments including an evacuation lumen for receiving a liquid cutting jet, plugging of the evacuation lumen can be prevented by constructing the evacuation lumen receiving the liquid cutting jet to have a region that is within and/or downstream of the jet-receiving opening that is designed to be able to macerate at least a portion of the tissue trained by the liquid jet into a plurality of particles when the instrument is in operation. The term "macerate" as used herein refers to a disaggregation of entrained material, for example an entrained tissue, by a liquid within the evacuation lumen undergoing intensely turbulent flow that creates a region of extremely high fluid shear and impacting forces capable of partitioning the material into particles having a size small enough to pass through the evacuation lumen without plugging the lumen. In preferred embodiments, the evacuation lumen is able to macerate a substantial fraction of the tissue entrained into a plurality of essentially microscopic particles. "Microscopic" as used herein refers to particles having a dimension too small to be visualized unaided by the human eye.

Prevention of blow-by (defined as a portion of a liquid cutting jet or high velocity fluid entrained by the liquid cutting jet having a cross-sectional area, at the plane of the jet-receiving opening, that is larger than the cross-sectional area of the jet-receiving opening so that at least a portion of the liquid cutting jet or high velocity fluid misses or "blows by" the jet-receiving opening) can be accomplished by providing a surgical jet instrument having a distal end configured so that, when in operation, the liquid cutting jet and the high velocity fluid entrained by the liquid cutting jet occupies a substantial fraction of the cross-sectional area of the jet-receiving opening, but does not occupy a region larger than the cross-sectional

requiring the rotatable shaft, the shaft may be deployed into the surgical operating field, but during a procedure requiring use of only the liquid cutting jet, the rotatable shaft may be withdrawn from the surgical field, if desired.

For instruments provided according to the invention including a rotatable shaft therein, the proximal end of the rotatable shaft is typically disposed within a body or at a user-controllable proximal end of the instrument. The proximal end of the shaft is drivingly coupled to a mechanism that is constructed and arranged to impart a rotating motion to the rotatable shaft. The term "drivingly coupled" as used herein refers to the shaft being interconnected with a drive mechanism such that motion of a component of the drive mechanism imparts rotational motion to the rotatable shaft. Such coupling can be accomplished, as would be apparent to those of ordinary skill in the art, by a variety of means such as, but not limited to, gear drives, belt drives, chain drives, friction drives, etc. The drive mechanism utilized to rotate the rotatable shaft within the instrument can comprise one or more of a variety of drive mechanisms including, but not limited to, electric motors, pneumatic turbines, etc., as apparent to those of ordinary skill in the art. However, in preferred embodiments, the invention utilizes an inventive liquid jet-driven rotatable rotor, preferably positioned within the body or at the proximal end of the instrument, to impart rotational motion to the rotatable shaft.

Preferred embodiments of the liquid jet-driven rotatable rotor mechanism provided according to the invention utilize a pressure lumen, having a liquid jet forming nozzle at a distal end thereof, to direct a liquid jet so that it impacts an impacting surface on the rotatable rotor, thus driving rotation of the rotor, which, in turn, creates a corresponding rotation of the rotatable shaft that is drivingly coupled thereto. Unlike typical prior art fluid driven turbine mechanisms, the preferred shaft-drive mechanism provided according to the invention does not utilize an expanding gas or, as is the case with typical prior art liquid-driven turbines, confine the rotor and liquid flow path within in an enclosed duct or channel such that the rotor is essentially completely submerged in a liquid during its rotation. In such typical prior art "reaction" turbines, the liquid driving the rotor undergoes a substantial change in hydrostatic pressure while in contact with the driving surface of the rotor. In contrast, the liquid jet-driven rotatable rotor mechanism provided according to the invention preferably maintains the liquid jet-driven rotor within a surrounding gaseous environment while it is being rotatably driven by a liquid jet during operation, so that essentially no part of the rotor is submerged in liquid during operation. In other words, the liquid that is in contact with the

surgical devices employ a turbine-driving fluid stream that is confined within a channel and utilize the acceleration of the fluid, while it is in contact with a turbine or rotor, characterized by a change in the hydrostatic pressure of the fluid while in contact with the turbine/rotor, to drive rotation of the turbine/rotor. The present inventors have determined that the preferred liquid jet-driven rotor mechanism provided according to the invention can, under certain conditions, provide improved efficiency of operation as well as improved torque vs. load characteristics, as compared with prior art mechanisms.

Also, as described in more detail below, for many embodiments of the invention, it is often desirable to provide a mechanism for drivingly coupling a liquid jet-driven rotor to a rotatable shaft of a surgical instrument so that the rotational speed of the rotatable shaft is different from that of the rotational speed of the liquid jet-driven rotor. Such rotational speed-changing drive mechanisms are well know to those of ordinary skill in the art. In the context of the present invention, a preferred drive coupling mechanism utilizes a gear reduction drive. The gear reduction drives utilized according to the invention can be configured in a variety of forms as apparent to those of ordinary skill in the art, including, but not limited to, screws and worm gears, helical gears, spur gears, etc. Some preferred embodiments of the invention utilize a gear reduction drive coupling mechanism providing a rotational speed of the rotatable shaft that is a defined fraction of the rotational speed of the liquid jet-driven rotatable rotor. By utilizing such a gear reduction mechanism, the maximum torque obtainable at the distal end of the rotatable shaft for rotating a tissue contacting surgical component, such as a grinding burr, can be larger, by a factor of the degree of gear reduction, than the torque that would be obtainable utilizing a direct drive coupling mechanism with the same diameter rotatable rotor. This can enable the use of a smaller diameter rotatable rotor for obtaining a particular value of maximum torque under maximum load conditions (i.e., when the rotatable shaft is completely stalled so that its rotational speed is essentially zero). As will be discussed in more detail below, a particularly advantageous configuration of a driving mechanism for providing rotary motion to the rotatable shaft, according to the invention, utilizes a liquid jet-driven rotatable rotor that rotates about an axis of rotation that is essentially perpendicular to the axis of rotation of the rotatable shaft (defined by the longitudinal axis of the shaft) of the surgical instrument. This configuration provides a compact and effective means for coupling rotation of the rotatable rotor to the rotatable shaft through the gear reduction mechanism.

other embodiments, a pressure lumen together with a target or evacuation lumen positioned opposite the pressure lumen to receive a liquid cutting jet.

In the illustrated embodiment, surgical instrument 100 further includes a sheath 132 which at least partially surrounds pressure lumen 118, evacuation lumen 120, and rotatable shaft 124. As explained in more detail below, sheath 132 aids in supplying support for the lumen to assist in maintaining and/or establishing a desired geometric configuration between pressure lumen 118 and evacuation lumen 120 to prevent relative motion of the lumen and misdirection of a liquid cutting jet. In addition, sheath 132 can be used for providing support and evacuation to distal end 130 of rotatable shaft 124. As discussed in more detail below in the context of FIGs. 2A-2C, removably coupled to distal end 116 and sheath 132 is burr tip support 136 including a snap tab 138 which fits into snap-lock slot 140 on sheath 132 to enable removable coupling thereto. Burr tip support 136 also serves to provide a bearing surface for distal end 130 of rotatable shaft 124, as well as to provide support to pressure lumen 118 and evacuation lumen 120.

Proximal end 142 of sheath 132 is sealingly coupled to the distal end of collar 144, whose function will be more thoroughly explained in the context of FIG. 4 below. Collar 144 includes a seating flange 146 which is held in place by slots 148 in body 104 when the instrument is assembled. Flange 146 also includes projecting ridge 150 which mounts within a complementary groove within body 104, in order to prevent collar 144 from rotating during operation of the instrument.

Contained within body 104 of instrument 100 is driving mechanism 152 configured for driving rotatable shaft 124. The specific details of the structure and operation of driving mechanism 152 are described in more detail below in the context of FIGs. 8A-8E. Drive mechanism 152 includes a liquid jet-driven rotor and gear reduction mechanism, shown and described in more detail below, enclosed in a three-part rotor housing 154 held together by screw fasteners 156 and comprising an upper rotor housing cap 158, a rotor housing block 160, and a rotor housing bottom component 162. High pressure liquid is supplied to drive mechanism 152 via rotor drive pressure lumen 164. Rotor housing 154 is evacuated of liquid via rotor jet evacuation lumen 166, rotor housing block evacuation conduit 168, and rotor housing bottom evacuation conduit 170. Also visible in FIG. 1 is rotor bearing 172. Bearings for use in the current invention for rotatably mounting a rotor or components of drive mechanism 152 coupled to rotatable shaft 124 can comprise any suitable type of

FIG. 2A is an exploded perspective view of the portions of surgical instrument 100 disposed distal to body 104. As illustrated in FIG. 2A, rotatable shaft 124, pressure lumen 118 and evacuation lumen 120 are shown removed from sheath 132 for clarity. Pressure lumen 118 and evacuation lumen 120 are preferably constructed from a surgical grade stainless steel, however, in alternative embodiments, either or both of the lumen may be constructed from other suitable materials, for example certain polymeric materials, as apparent to those of ordinary skill in the art. Regardless of the specific material from which the pressure lumen is constructed, pressure lumen 118 (as well as pressure lumen 164 supplying drive mechanism 152) must have sufficient burst strength to enable the lumen to conduct a high pressure liquid to the nozzle, for example nozzle 192, at the distal end of the pressure lumen in order to form a liquid jet. The burst strength of the pressure lumen utilized in the surgical instrument should be selected to meet and preferably exceed the highest contemplated pressure required for use in the specific surgical procedure to be performed. Typically, surgical instrument 100 will operate at liquid pressures of between about 500 psig and about 50,000 psig, depending on the intended material to be cut and/or ablated and/or the required rotational speed and maximum torque of the rotatable shaft. Those of ordinary skill in the art will readily be able to select appropriate materials for forming the pressure lumen of the instrument and the evacuation lumen for particular surgical requirements based on the functional requirements of each described herein.

Also illustrated in FIG. 2A is a preferred configuration for supporting rotatable shaft 124 and lumens 118 and 120 within sheath 132. Rotatable shaft 124 includes a coupling region 200, having a reduced cross-sectional area and a non-circular cross sectional shape, disposed at its proximal end. Coupling region 200, as described in more detail below, enables rotatable shaft 124 to be coupled in driving engagement with shaft drive mechanism 152. Supporting the distal end 130 of rotatable shaft 124 is burr tip support 136. Shown in more detail in FIG. 2B and FIG. 2C, burr tip support 136, when assembled, provides a central shaft bearing region 202 surrounding a region 204 of rotatable shaft 124 having a circular cross sectional shape and a reduced cross sectional dimension when compared to the central region 205 of rotatable shaft 124. Region 204 is surrounded by shaft distal bearing region 202 of burr tip support 136 and rotates therewithin, when the instrument is in operation. Longitudinal movement of rotatable shaft 124 with respect to burr tip support 136 and sheath 132 is prevented by shaft bearing flange 206 and bearing lip 208 of rotatable shaft 124.

envision a variety of alternative means for providing exchangeability of rotatable shaft 124 of instrument 100, all of which are deemed to be within the scope of the present invention.

Upon assembly, burr tip support 136, in addition to providing a distal bearing for rotatable shaft 124, also supplies support for pressure lumen 118 and evacuation lumen 120 to assist in maintaining and/or establishing a desired geometric configuration between the pressure lumen and the evacuation lumen when instrument 100 is in operation. In preferred embodiments, pressure lumen 118 and evacuation lumen 120 are supported by burr tip support 136, when the instrument is assembled, so that the distal ends of the lumen are sufficiently stiff to prevent deflection of the lumen, by, for example, contact with surfaces within the surgical operating space, which deflection could potentially lead to misdirection of the liquid cutting jet formed by nozzle 192 as high pressure liquid flows therethrough so that the cutting jet is no longer incident upon jet-receiving opening 193 in evacuation lumen 120, thus potentially causing unintended tissue damage to the patient.

FIG. 3 is a perspective view showing surgical instrument 100 as viewed from a proximal end thereof. FIG. 3 illustrates the assembled surgical instrument except excluding body 104 to show the internal components with greater clarity. The particular view illustrated shows more clearly the back view of shaft drive mechanism 152 showing shaft drive bearing 230 as well as the locations for attachment to rotor drive jet evacuation lumen 166, rotor housing block evacuation conduit 168, and rotor housing bottom evacuation conduit 170. Also shown more clearly is high pressure conduit 184 and evacuation conduits 178. High pressure liquid supply conduit 184 must have a burst strength capable of withstanding the highest liquid pressures contemplated for using instrument 100 for a particular surgical application. In some embodiments, high pressure liquid supply conduit 184 comprises a burst-resistant stainless steel hypotube constructed to withstand at least 50,000 psig. In some embodiments, the hypotube may be helically coiled to improve the flexibility and maneuverability of surgical instrument 100. In preferred embodiments, especially those including integrated electrocautery as discussed below, high pressure liquid supply conduit 184 is comprised of an electrically insulating material such as a Kevlar®-reinforced nylon tube. The liquid contained in evacuation conduits 178 (as well as evacuation conduits 168, 170, and 174 within the body of the instrument) is under relatively low pressure and, accordingly, the evacuation conduits may be constructed, in preferred embodiments, of a low cost flexible material, for example, polymeric tubing such as polyvinyl chloride (PVC), silicone, polyethylene, rubber, etc., tubing. Evacuation lumen 120

respectively. In order to prevent leakage of evacuated fluid and a loss of suction through grooves 254 and 256 during operation of the device, a bead of sealant 258 can be used to surround the lumen and create a vacuum-tight seal with inner sealing surface 250 of collar 144, upon assembly of the device. Such sealant can be comprised of a polymeric foam or RTV sealant, as would be apparent to those of ordinary skill in the art.

Proximal end 248 of rotor housing base 162 further includes a sheath evacuation channel 260 machined therein for providing a fluid flow path for transport of fluid and debris between cavity 262, comprising a sheath evacuation region, and evacuation conduit 174. During operation of the device, when a suction is applied to evacuation conduit 174, liquid and debris will flow into sheath 132 via evacuation channel slots 218 of burr tip support 136, then through bore 240 of collar 144 into sheath evacuation cavity 262, through sheath evacuation channel 260, and finally through evacuation conduit 174 for removal from the instrument.

Also shown in FIG. 4 are rotor jet pressure lumen mounting blocks 264, 266 which are utilized to mount rotor drive pressure lumen 164 to rotor housing block 160 via, for example, screws 268. As described in more detail below, the rotor jet pressure lumen mounting blocks enabled precise alignment and direction of the liquid jet formed by the nozzle of pressure lumen 164 onto an impacting surface of a rotor utilized for driving rotatable shaft 124, when the device is in operation.

FIG. 5A illustrates an alternative embodiment for configuring the distal end of a surgical instrument providing both a liquid cutting jet and a rotational grinding burr and also more clearly illustrates a preferred configuration for providing a liquid cutting jet nozzle and evacuation lumen distal end. Instrument 272 includes a proximal end 274 and a distal end 276. Unlike the previously illustrated embodiment, instrument 272 includes a sheath 278 surrounding only rotatable shaft 280 including, at its distal end, a grinding burr 282. Surgical instrument 272 further includes a pressure lumen 284 and an evacuation lumen 286, both of which are disposed external to sheath 278.

For embodiments of the invention utilizing rotating shafts including grinding burrs at their distal ends, a wide variety of grinding burrs can be utilized depending on the needs of the particular surgical application, as would be apparent to those of ordinary skill in the art. For example, fluted burrs and diamond burrs of various shapes and sizes can be used. For example, spherical, cylindrical, oval, flat, pear or egg shaped burrs may be utilized of various sizes for particular surgical applications. Typical burr sizes for use, for example, in bone

region, the more narrowly focused and collimated will be the liquid jet that is emitted from the jet opening of the nozzle. For reasons described in more detail below, highly collimated liquid jets are preferred both for forming liquid cutting jets at the distal end of the inventive surgical instruments and for driving rotational motion of rotatable rotors and shafts provided by the inventive surgical instruments. However, in general, nozzles with ratios of length to minimum internal diameter that are very high, for example greater than about 10, tend to create a very high pressure drop through the nozzle during use without significantly improving the degree of collimation of the jet and, therefore, are less preferred for use in the inventive surgical instruments than nozzles having a ratio of length to minimum internal diameter of an intermediate value, for example about 6.

The present invention provides surgical liquid jet instruments which are specifically designed and constructed for use in a particular surgical environment. Specifically, certain embodiments of the invention provide surgical liquid jet instrument designs that are tailored to provide highly desirable liquid jet cutting characteristics in surgical operating environments where the liquid jet is submerged in a liquid environment when the instrument is in operation. More specifically, the invention provides, in such embodiments, surgical liquid jet instruments including pressure lumen and evacuation lumen that are shaped, and positioned relative to each other, to establish certain predetermined geometric relationships between the jet forming components and jet-receiving components that are specifically selected to provide the desired performance characteristics of the instrument in a liquid surgical environment.

Reference is made in FIG. 6A for describing the operation and design characteristics of preferred devices for use in forming a liquid cutting jet that is submerged in a surrounding liquid-containing surgical environment. FIG. 6A shows a partially cutaway view of the distal ends of pressure lumen 118 and evacuation lumen 120, which can form part of a surgical instrument, for example such as that shown previously in FIG. 1. Prior to operation, the distal ends of pressure lumen 118 and evacuation lumen 120 would be inserted into the operating field and at least partially submersed in a liquid 300 therein so that at least nozzle 192 and jet-receiving opening 193 are completely surrounded by liquid 300. When the instrument is in operation, liquid under high pressure is delivered via pressure lumen 118 to nozzle 192, causing jet opening 294 to create a liquid cutting jet 296 as the high pressure liquid streams therethrough. As mentioned previously, it is preferred that the jet 296 is substantially collimated as it exits jet opening 294. The more collimated a liquid jet, the less

evacuation lumen, and inefficient tissue/debris entrainment and removal. Also, as previously mentioned, in preferred embodiments, it is desirable that ablated tissue and debris be evacuated from the surgical site through the evacuation lumen, without the need for a source of external suction to be applied to the proximal end of the evacuation lumen. In order to provide the above-mentioned characteristics, the inventive surgical instruments for use in a liquid environment can include an evacuation lumen having specifically selected predetermined shapes and configurations, which is positionable relative to the jet opening at a specific predetermined distance. Specifically, in preferred embodiments, jet-receiving opening 193 is positioned, when the instrument is in operation, opposite jet opening 294, at a predetermined distance ℓ therefrom, and provided in a nozzle 192 having a length to minimum diameter ratio so that essentially all of the fluid in liquid cutting jet 296 enters jet-receiving opening 193. As discussed above, liquid cutting jet 296 will tend to create entrainment region 302 surrounding the liquid cutting jet 296 when the instrument is in operation. Entrainment region 302 will typically be symmetrically deposed around liquid cutting jet 296 and will tend to diverge in a direction from jet opening 294 to jet-receiving opening 193. In typical embodiments where jet opening 294 is circular in shape, entrainment region 302 will have a truncated cone shape, having a truncated apex at jet opening 294 and a base defined as a cross section of the cone at the plane of jet-receiving opening 193. In preferred embodiments, the base of entrainment region 302 occupies between about 50% and about 100% of the cross-sectional area of jet-receiving opening 193 when the instrument is in operation, more preferably the entrainment region occupies at least about 75%, more preferably still at least about 90%, and most preferably at least about 95% of the cross-sectional area of jet-receiving opening 193 when the instrument is in operation.

As shown in FIG. 6C, the cross-sectional area of the jet-receiving opening 193 required to ensure that the entrainment region 302 occupies the desired relative fraction of the cross-sectional area of the jet-receiving opening 193, as discussed above, is functionally related to the chosen predetermined distance ℓ between the jet opening 294 and the jet-receiving opening 193 and the degree of divergence characterizing the entrainment zone (represented by angle ϕ in FIG. 6C). Specifically, the desired cross-sectional radius b of the base of the entrainment region 302 at the jet-receiving opening 193 is related to predetermined distance ℓ and the degree of divergence of the entrainment region by $b = \ell \tan \phi$. Predetermined distance ℓ is typically selected based on the desired use of the surgical

In order to provide a maceration region, evacuation lumen 120 preferably includes a jet-deflecting portion 308 that is located adjacent to and downstream of jet-receiving opening 193. Jet-deflecting region 308 may be either a straight surface that is angled with respect to the direction of at least a central portion of liquid cutting jet 296, or in preferred embodiments, jet-deflecting region 308 comprises a smoothly curved surface upon which at least a portion of liquid cutting jet 296 impinges, where the curved surface is shaped to deflect at least a portion, and preferably all of the liquid cutting jet 296 and liquid comprising entrainment region 302 in a direction that is essentially parallel to the longitudinal axis 312 of evacuation lumen 120 in the region proximal to the jet-deflecting region 308. In preferred embodiments, the radius of curvature of the curved surface defining jet-deflecting region 308 is essentially constant, having a value of between about 0.5 and about 20 times the internal diameter of evacuation lumen 120. In one preferred embodiment, the radius of curvature of the curved surface defining jet-deflecting region 308 is essentially equal to the internal diameter of evacuation lumen 120 at jet-deflecting region 308, so that essentially no portion of jet-receiving opening 193 projects radially beyond a perimeter defined by an outer surface 314 of a portion of the evacuation lumen located proximal and adjacent to jet-deflecting region 308. It is also generally preferable for the surgical instruments provided by the invention that the liquid cutting jet be directed into the jet-receiving opening so that a direction of at least a central portion of the liquid cutting jet forms an angle of no greater than about 20 degrees, and more preferably no greater than about 10 degrees, with respect to a line normal (i.e., perpendicular) to a plane defining (i.e., co-planar to) the jet-receiving opening. In the most preferred embodiments, the central portion of the liquid jet is essentially parallel to a line that is normal to the plane defining the jet-receiving opening.

In order to provide effective eductor pump action of evacuation lumen 120, in some embodiments, evacuation lumen 120 will have an essentially constant internal cross-sectional area from jet-receiving opening 193 to a position that is proximal to the distal end of the surgical instrument where the proximal end of the evacuation lumen is located. In other embodiments, eductor pump action can be enhanced by providing an evacuation lumen having an essentially constant cross-sectional area and having a jet-receiving opening, which has a cross-sectional area that is less than the cross-sectional area of the evacuation lumen (i.e., the internal cross-sectional area of the evacuation lumen has a minimum value at the jet-receiving opening). In yet other embodiments, eductor pump action can be enhanced by providing an evacuation lumen having an internal cross-sectional area which increases

from an area surrounding the distal end of the rotatable shaft. FIG. 7A shows a partial section of a distal region of rotatable shaft 400 that is constructed and arranged to generate an evacuation force tending to drive liquid and debris from the distal end of a sheath surrounding shaft 400, when it is assembled within a surgical instrument according to the invention, to the proximal end of such sheath. "Constructed and arranged to generate an evacuation force" as used herein in the present context refers to the ability of a rotatable shaft, rotating either within a surrounding sheath or without a surrounding sheath, to be able to drive liquid from a region near the distal end of the rotatable shaft towards the proximal end of the rotatable shaft and out of a surgical field into which a distal end of the rotatable shaft is placed, without the need for an external source of suction.

In operation, rotatable shaft 400 rotates in a direction shown by arrow 402. Rotatable shaft 400 includes a portion 404 of increased cross sectional dimension, preferably having a cross sectional dimension only slightly less than an internal cross sectional dimension of a surrounding sheath in which rotatable shaft 400 is disposed when assembled into a surgical instrument. Region 404 includes a helically grooved channel 406 machined therein. Both region 404 and channel 406 are positioned on shaft 400 so that they are surrounded by a sheath when assembled into a surgical instrument. Rotation of shaft 400 in the direction of arrow 402 during operation creates a driving force tending to move fluid and debris from the distal end of shaft 400, in proximity to grinding burr 408, to a proximal end of the shaft and out of the surgical field in which burr 408 is operating.

FIG. 7B shows a partial view of a distal region of an alternative embodiment of a rotatable shaft 410 that is constructed and arranged to generate an evacuation force upon rotation in the direction of arrow 412. Shaft 410 includes grinding burr 414 at a distal end thereof, and further includes impellers 416, which are disposed within a surrounding sheath when shaft 410 is assembled into a surgical instrument, according to the invention. Upon rotation within the surrounding sheath, impellers 416 generate an evacuation force tending to drive liquid and debris towards the proximal end of the shaft during operation of the instrument.

FIG. 7C shows yet another embodiment of a rotatable shaft constructed and arranged to generate an evacuation force upon rotation. Rotatable shaft 416, having grinding burr 418 at a distal end thereof, has an interior that is hollow forming a channel 420, which extends distally up to at least aperture 422 in scoop 424 (scoop 424 together with aperture 422 will be hereinafter collectively referred to as a "scoop-shaped aperture" 425). Aperture 422 is in

assembly 468 (shown more clearly in an assembled state in FIG. 8B). Gear reduction mechanisms utilizing worm gears, such as illustrated in FIG. 8A, are preferred for some embodiments because they provide relatively high gear reduction ratios for their size. In other embodiments, where a lower degree of gear reduction and a lower difference in rotational speed between rotatable rotor 450 and drive shaft 470 of rotatable shaft drive assembly 468 is required or desired, other means of gear reduction, for example spur gears, helical gears, or any other suitable gear reduction mechanisms apparent to those of ordinary skill in the art can be utilized. In addition, for embodiments where high speeds are required or desired or only low torques are necessary during operation, the gear reduction mechanism may be eliminated entirely and the rotatable rotor assembly 454 may be utilized to drive rotatable shaft 124 directly. In such an embodiment, rotatable shaft drive mechanism 152 could dispense entirely with rotatable shaft drive assembly 468, and instead couple the rotatable shaft 124 directly to rotatable rotor assembly 454. Of course, in such embodiments, it is desirable to position rotatable rotor assembly 454 so that its longitudinal axis 472 is aligned parallel to longitudinal axis of rotatable shaft 124 (i.e., it would be desirable to orient rotatable rotor assembly 452 in the orientation currently shown for rotatable shaft drive assembly 468 in FIG. 8A).

Rotatable shaft drive assembly 468, as illustrated, is comprised of drive shaft 470 to which is attached worm wheel 466. The assembly also includes two shaft drive bearings 230 and 474 which permit rotation of drive shaft 470 upon assembly of rotatable shaft drive mechanism 152. Bearings 230 and 474 are held by flanges (e.g., 476) provided in the housing components, upon assembly of the mechanism. Bearings 172, 456, 230, and 474, as illustrated, comprise ball bearings; however, in alternative embodiments the bearings may comprise journal bearings, hydrodynamic bearings, or any other suitable bearings as apparent to those of ordinary skill in the art.

The components comprising rotatable shaft drive mechanism 152 are preferably formed from a rigid, durable material, such as a variety of metals, for example surgical grade stainless steel. Because rotatable rotor assembly 454 and rotatable shaft drive assembly 468 rotate at high velocity during operation of the instruments, it will be apparent to those of ordinary skill in the art that the rotatable rotor 450, worm wheel 466, and other components comprising the assemblies should be properly balanced so that they can rotate at high rotational speeds without undue vibration of the instrument. Rotatable shaft drive assembly 468 further includes attached to its distal end rotatable shaft mounting component 480 having

other embodiments at least about 65,000 RPM, in yet other embodiments at least about 130,000 RPM, in yet other embodiments at least about 250,000 RPM, and in still other embodiments at least about 500,000 RPM. The diameter of rotatable rotor 450 is typically at least about 0.5 inch, in other embodiments at least about 1 inch, in other embodiments at least about 2 inches, in other embodiments at least about 5 inches, and in yet other embodiments at least about 10 inches. The gear reduction mechanism is selected and configured in preferred embodiments, so that the rotational speed of rotatable rotor 450 will exceed the rotational speed of drive shaft 470 of rotatable rotor drive assembly 468. In typical embodiments, the rotational speed of rotatable rotor 450 will exceed that of drive shaft 470 by at least about a factor of 2, in other embodiments by at least about a factor of 5, in other embodiments by at least about a factor of 10, in other embodiments by at least about a factor of 20, and in yet other embodiments by at least about a factor of 30. In one particularly preferred embodiment involving a surgical instrument including a rotatable shaft having a 5 mm diameter fluted burr at a distal end thereof , which is utilized for bone grinding in a surgical operating field, rotatable rotor 450 comprises a 1 inch diameter saw-tooth rotor having between about 10 and 200 teeth, and in one preferred embodiment about 80 teeth, which is driven at a rotational speed during operation of about 130,000 RPM and is coupled to drive shaft 470 via a worm-gear reduction mechanism such that the rotational speed of drive shaft 470 is about 1/10th that of rotatable rotor 450 during operation.

For embodiments utilizing a rotatable rotor which is a saw-tooth rotor, depending on the diameter of the saw-tooth rotor and the size of the teeth when compared to the diameter of the rotor, the number of teeth provided on the rotor can range from about 10 to about 200. As discussed immediately above, one particularly preferred saw-tooth rotor embodiment comprises a 1 inch diameter rotor having a thickness of about 0.040 inch and having about 80 teeth therein, each tooth providing a jet impacting surface about 0.040 inch wide by 0.040 inch in height.

FIGs. 8C-8E are detailed views of rotatable rotor 450 and rotatable rotor assembly 454 showing the configuration of the rotatable rotor with relation to liquid jet forming nozzle 490 and rotor jet evacuation lumen 166, when rotatable shaft drive mechanism 152 is assembled. For clarity, components other than the rotatable rotor assembly, pressure lumen and evacuation lumen are not shown in the figures. Referring to FIG. 8C, rotatable rotor 450 comprises a saw-tooth rotor including a plurality of teeth 498 each including an essentially planar impacting surface 500 upon which liquid jet 502 impacts, when the instrument is in

of operation of the instrument where the rotatable shaft of the instrument is subjected to significant torque tending to inhibit its rotation. During such periods of operation, rotatable rotor 450 will tend to rotate at a speed that is less than the velocity of liquid jet 502. Under such conditions, liquid jet 502 can have a tendency to form spray or mist upon impacting an impacting surface 500. By contrast, under conditions of free rotation, rotatable rotor 500 rotates at a speed essentially equal to the speed of liquid jet 502, so that the trajectory of liquid jet 502 remains essentially constant even after impacting an impacting surface 500, and minimal spray is created. In an alternative embodiment, the evacuation lumen can be configured and positioned so that it does not surround and enclose any portion of the distal end of pressure lumen but, instead, is positioned distally of the nozzle in the pressure lumen, preferably with a jet-receiving opening positioned within about 0.01 inch of the jet opening in the nozzle.

The design of evacuation lumen 166 as illustrated enables effective evacuation of essentially all of the liquid comprising liquid jet 502 from the housing enclosing the rotatable rotor assembly during operation of the device under a wide range of loads and resistances applied to the rotatable shaft of the instrument. In certain embodiments, the proximal end of evacuation lumen 166 can be placed in fluid communication with a source of external suction in order to effect evacuation of liquid comprising liquid jet 502. In some preferred embodiments, liquid jet 502, via eductor pump action, described previously, is able to create its own evacuation force tending to evacuate the liquid comprising liquid jet 502, together with any spray formed upon impacting with a surface of the rotor, from the distal end of evacuation lumen 166 without the need for an external source of suction.

In typical embodiments, jet opening 492 in nozzle 490 has a diameter of between about 0.001 and about .02 inch, more preferably between about 0.003 and 0.01 inch, and in one preferred embodiment has a diameter of about 0.005 inches. In typical embodiments, liquid is supplied to nozzle 490 to form a liquid jet at a pressure of at least about 1,000 psig, in other embodiments at least about 5,000 psig, in another embodiments at least about 15,000 psig, and yet in other embodiments, at least about 30,000 psig. In one preferred embodiment, liquid is supplied to nozzle 490 to form a liquid jet at a pressure of about 8,000 psig. Evacuation lumen 166, in typical embodiments, has a jet receiving opening 508 having a diameter of between about 0.01 and about 0.3 inches, more preferably between about 0.05 and about 0.2 inches and in one preferred embodiment about 0.12 inches. As will be discussed below in more detail in the context of FIGs. 11A-11B, for embodiments wherein

tangent to the circle circumscribed by the outermost perimeter of the rotor as it rotates about its axis of rotation 518. In some especially preferred embodiments, each liquid jet impacting surface 500 of rotatable rotor 450 is oriented essentially perpendicularly to line 516

In alternative embodiments, a rotor having liquid jet impacting surfaces that are curved may be utilized in place of a saw tooth rotor having planar impacting surfaces, as previously described. FIG. 10A shows a perspective view of a curved-vane rotor 520 having curved liquid jet impacting surfaces 522. Curved impacting surfaces 522 are defined by a series of curved vanes 524 positioned along the periphery of rotor 520. As illustrated, preferred curved-vane rotors have impacting surfaces 522 that are oriented to provide an impacting surface that is concave with respect to the direction of an incoming liquid jet, shown by arrow 526. In the illustrated embodiment, curved impacting surfaces 522 comprise semi-cylindrical surfaces. For embodiments utilizing rotors having smoothly curved liquid jet impacting surfaces 522, it is preferred for the liquid jet to be oriented in a direction 526 such that it is directed toward surface 522 essentially tangentially to the surface.

FIG. 10B illustrates a particularly preferred configuration for orienting and positioning curved vanes 524 around the periphery of rotor 520. As illustrated in FIG. 10B, in a preferred embodiment, angle α formed between the line 523 tangent to impacting surface 522 of the curved vane and the line 525 defining the edge of rotor 520 should be between about 5 degrees and about 30 degrees, and in a preferred embodiment is about 17 degrees. In addition, channel width *h* between curved vanes 524, through which the liquid comprising an impacting liquid jet flows when the rotor is in operation, is preferably between about the diameter of the impacting liquid jet at the point of impact and a value of about twice the diameter of the liquid jet. In addition, the width of curved vanes 524 (*C*) is preferably chosen with respect to the inter-vanes spacing (*S*) such that the ratio (*C/S*) is between about 1.0 and about 1.5. In yet other embodiments, a smoothly curved jet impacting surface may be provided by utilizing a Terry rotor for driving the rotatable shaft of the surgical instrument. Terry rotors are known in the mechanical arts and are described in greater detail in, for example, Balje, O.E. *Turbomachines: A Guide to Design, Selection, and Theory,* John Wiley & Sons, New York, NY, 1981, pp. 252-256.

FIGs. 11A and 11B show two potential configurations for supplying evacuation to the various evacuation lumen and conduits of surgical instrument 100. In another embodiment, not illustrated, an external source of suction is coupled in fluid communication to each of the

rotor housing block 160 and evacuation conduit 170 connected to the rotor housing base 162 of the surgical instrument.

A cross-sectional view showing the internal details of liquid flow directing valve 180 is illustrated in FIG. 12. Liquid flow directing valve 180 includes a valve body 550 formed of a rigid sturdy material, for example surgical grade stainless steel, having a centrally disposed bore therein forming a cylinder 552 internal to valve body 550. Valve 180 is configured as a slidable three-way valve. Valve body 550 further includes an inlet 182 comprising a bore having threaded walls configured to mate with a high pressure tubing coupling 186 (shown in FIG. 1). Similarly, valve body 550 further includes a first 188 and a second 194 outlet configured with internally threaded surfaces for coupling to high pressure connectors 190 and 196 respectively.

Disposed within centrally disposed cylinder 552 is a shaft 554, preferably comprised of a rigid, durable metal such as surgical grade stainless steel, connected by threads 555 at each end to user actuated knobs 197. Also disposed on shaft 554 are two elements 556 comprising pressure tight sealing components for preventing leakage of high pressure liquid from and within valve 180. Elements 556 comprising the pressure tight sealing components are described in greater detail below in the context of FIGs. 13A and 13B. Elements 556, while shown for use within the context of liquid flow directing valve 180, can also be used for a wide variety of other applications where a high pressure, slidable sealing component is needed to form a high pressure seal between a shaft or piston and the walls of a cylinder. Pressure tight sealing components 556 are separated along shaft 554 by a cylindrical spacer sleeve 558 surrounding shaft 554 and disposed between the pressure tight sealing components. Pressure tight sealing components 556 are forced against spacer 558 to prevent relative motion between shaft 554 and the pressure tight sealing components by tightening knobs 197 onto the threaded ends of shaft 554 to provide a biasing force pushing the pressure tight sealing components 556 against spacer 558.

Spacer 558 has an external diameter less than that of the internal diameter of inner surface 560 of cylinder 552. Thus, a space provided between the outer surface 562 of spacer 558 and the inner surface 560 of cylinder 552 defines a flow channel 564 through which high pressure liquid flows from inlet 182 to either or both of outlets 188 and 194, when the instrument is in operation. In some preferred embodiments, valve 180 can be adjusted by the user, by manipulating the position of shaft 554 with knobs 197, to provide three user-

to a component that is able to form a pressure-tight seal between two regions of a cylinder, each containing a fluid therein, wherein the fluids contained in the two regions are at different hydrostatic fluid pressures. A "fluid" when in the present context can comprise a liquid, gas, supercritical fluid, slurry, suspension, or any mixture of the above, and refers to the thermodynamic state of the material present in the regions of the cylinder at the temperature and pressure at which the component is used in operation. In the context of use of the pressure-tight sealing component within liquid flow control valve 180, the fluid contained in at least one of the above-mentioned regions of the cylinder will comprise a liquid; however, as apparent to those of ordinary skill in the art, element 556 can also be used for a wide variety of other pressure sealing applications not necessarily involving pressurized liquids.

Element 556 is shown in cross section of Fig. 13 together with a portion of spacer 558. Shaft 554 has been removed in the figure to show the illustrated components with greater clarity. Element 556 may be comprised of a wide variety of materials capable of withstanding the pressures contemplated, such as, for example, a variety of metals, ceramics, plastics, etc. Element 556 is, in preferred embodiments, comprised of a non-elastomeric, semi-rigid plastic that is dimensionally stable within the range of operating pressures contemplated. Preferred plastics include crystalline polymers or semi-crystalline polymers, or amorphous polymers having a glass transition temperature higher than the operating temperature of the apparatus utilizing element 556 as a sealing component. Element 556 can be constructed from a wide variety of engineering plastics, for example, polytetrafluorethylene (PTFE), polypropylene, polyethylene, polyvinylchloride, polyamides, polysulfone, polystyrene, mixtures thereof, etc., as apparent to those of ordinary skill in the art. In one particular preferred embodiment, element 556 is formed from an acetal polymer, for example, polyoxymethylene (Delrin™).

Element 556 includes an integral, flared sealing flange portion 559 that is constructed and arranged to make sealing contact with the internal surface 560 of cylinder 552 within valve 180, while preventing contact between internal surface 560 and both shaft 554 and between internal surface 560 and any other portion of element 556 outside of flange region 559. "Constructed and arranged to make sealing contact" as used herein in reference to flared sealing flange portion 559 refers to at least an outer surface 561 of the flange portion being sized and shaped to form an essentially continuous contact with inner surface 560 of cylinder 552 (i.e., having an outer perimeter with a shape essentially conforming to the shape of cylinder 552). It should be emphasized, that while, in the illustrated embodiment, the shape

Flared sealing flange portion 559 of element 556 has a predefined length 574 and is angled to extend away from outer surface 576 of main body portion 563 and toward inner surface 560 of cylinder 552 of valve 180 when the valve is assembled. The flared sealing flange portion 559 extends away from surface 576 of main body portion 563, as shown, to form a cantilevered circumferential flange around the periphery of element 556. A "cantilevered circumferential flange" refers to a flange that circumscribes the entire outer perimeter of the main body portion of the element and is attached to the main body portion along one of its sides, while having at least two additional sides or faces (e.g., surfaces 561, 577, and 578) not attached to or integral with the main body portion of the element (i.e., having a triangular cross-sectional shape or a trapezoidal or rectangular cross-sectional shape).

Predefined length 574 and minimum thickness 580 of sealing flange portion 559 tend to vary approximately linearly with the size of cylinder 552 in which sealing element 556 is disposed during operation. In one exemplary embodiment utilizing a Delrin plastic element having a main body portion with an external diameter D_I of about 0.182 inch that is used as a pressure-tight sealing component within a cylinder having an internal diameter of about 0.1875 inch, length 574 is about 0.025 inch and thickness 580 is about 0.003 inch.

Sealing element 556 has a second outer diameter D_O defined by an outermost periphery 582 of flange portion 559 that exceeds the outer diameter D_I of main body portion 562. When element 556 is disassembled from cylinder 552 of valve 180, outer diameter D_O of the outermost periphery 582 of flange portion 559 exceeds outer diameter D_I of main body portion 563 by at least about 1%, in other embodiments by at least about 3%, in other embodiments by at least about 5%, and in yet other embodiments by at least about 10%. In one preferred embodiment, outer diameter D_O exceeds diameter D_I by about 5%. Cylinder 552 of valve 180, containing element 556 upon assembly of the valve, has an internal diameter that exceeds outer diameter D_I of main body portion 563 but that is somewhat less than outer diameter D_O of outermost periphery 582 of flange portion 559 of element 556. It should be emphasized that outer diameter D_O of outermost periphery 582 of flange portion 559 as described herein refers to the diameter as measured with element 556 disassembled from valve 180 and not contained within cylinder 552. When element 556 is inserted into cylinder 552, flange portion 559, which is pivotally flexible with respect to main body portion 563, will tend to have a maximum outer diameter of outermost periphery 582 of flange portion 559 that is essentially equal to the inner diameter of cylinder 552. Referring

"source of ground potential" as used herein refers to an electrode, surface, terminal, etc., that is maintained at essentially ground potential during performance of electrocautery with a surgical instrument.

Preferred surgical instruments, according to the invention, including integrated electrocautery further include at least one lumen therein able to conduct an electrically conductive liquid to the distal end of the instrument for insertion into a surgical field. Such a lumen is able to add conductive liquid to the surgical field in order to maintain an electrocautery electrode at the distal end of the instrument submerged in an electrically conductive liquid so as to enable current flow from a positive electrocautery electrode to a source of ground potential within the environment of the surgical field during electrocautery. Especially preferred instruments including integrated electrocautery include a pressure lumen therein able to conduct a high pressure liquid to the distal end of the instrument and able to form a liquid cutting jet within the surgical field. Some preferred surgical instruments will also include an exhaust lumen with a jet-receiving opening, positioned opposite a jet opening in a nozzle region of the above-mentioned pressure lumen, for evacuation of liquid and debris from the surgical field. Some preferred embodiments of surgical instruments including integrated electrocautery can also include a rotatable shaft therein for powering a tissue contacting component, for example a grinding burr. Such an instrument was described previously in the context of FIG. 1 and is shown and described, as configured with integrated electrocautery below in the context of FIGs. 16A and 16B.

In general, the inventive configurations for providing integrated electrocautery described below may be utilized in a wide variety of surgical instruments capable of delivering a conductive fluid, such as physiological saline or lactated Ringer's solution, to a surgical field of a patient, as would be apparent to those of ordinary skill in the art. In other embodiments, where the distal end of the surgical instrument is utilized in surgical fields that are naturally submersed in conductive fluids or are perfused by other means with conductive fluids, the instruments provided by the invention including integrated electrocautery can lack lumen for delivering conductive fluid to the surgical field, but may instead comprise, for example, a surgical instrument providing only a rotatable shaft that is powered by a liquid jet-driven rotatable rotor positioned within the body of the instrument and drivingly coupled to the rotatable shaft, such that rotation of the liquid jet-driven rotatable rotor causes a corresponding rotation of the rotatable shaft of the instrument as well as rotation of a

used herein for describing certain coated regions of conductive lumen or other surfaces of the surgical instrument according to the invention refers to such surfaces being coated with an electrical insulator such that there is essentially no, or an acceptably low level of, electrical conduction between the coated region of the surface and another surface or medium through the electrically insulating layer at any electrical potentials up to the maximum electrical potential rating of the surgical instrument (about 1500 volts for typical electrocautery instruments as described herein). In other embodiments, the electrode(s) may comprise probes or conductive elements that are separate or separable from the fluid conducting lumen of the instruments.

An illustrative embodiment for a rotatably deployed surgical liquid jet instrument is shown in FIGs. 14A-14F. Referring to FIG. 14A, surgical instrument 600 includes a body 602 having a grasping region 604 configured to be held within the hand of an operator and an actuating element 606 that comprises a slidable sleeve or collar, which is used to deploy the distal end 608 of surgical instrument 600. Slidable sleeve 606 is positioned to be easily actuated by a single hand of an operator of instrument 600. Slidable sleeve 606 can enable the operator to hold body 602 in at least two different hand/grasping region 604 orientations, so that the operator can actuate slidable sleeve 606 while holding body 602 in either of the at least two hand/grasping region 604 orientations. For example, an operator can grip body 602 in a hand position where the thumb of the operator is located near the distal end of gripping region 604. In such position, the operator can actuate slidable sleeve 606 by moving the slidable sleeve with her thumb. In a second hand/grasping region orientation, the operator can grip body 602, for example, with her thumb positioned toward the proximal end of body 602, while actuating slidable sleeve 606 via one or more of the other four fingers of her hand.

Surgical instrument 600 also includes a collar 610 that is rotatably mounted within body 602. Rotatably mounted collar 610 is typically a cylindrically-shaped sleeve, which may be attached to, or form part of, sheath 612. Distal end 608 of surgical instrument 600 is shown in FIG. 14A in an undeployed configuration. Sliding sleeve 606 in the direction of arrows 614 causes a rotational motion of rotatably mounted collar 610 in the direction shown by arrows 616, which, in turn, causes a rotation of evacuation lumen 618 about a longitudinal axis of sheath 612, which is essentially parallel to the longitudinal axis of body 602 and the longitudinal axis of the portion of evacuation lumen 618 within sheath 612. In other embodiments, upon deployment, evacuation lumen 618 may rotate about the longitudinal axis of sheath 612, which is essentially collinear to the longitudinal axis to of the portion of

FIG. 14A shows the distal end of instrument 600 submersed in an electrically conductive fluid in a surgical field 626. Pressure lumen 620 is coated with insulating layer 626 except at its distal tip. The uncoated, uninsulated distal tip 622 forms the positive integrated electrocautery electrode. Evacuation lumen 618, in the illustrated embodiment, is uninsulated except at distal tip 630. In the illustrated embodiment, distal tip 630 of evacuation lumen 618 is insulated in order to increase the minimum length of the conductive path 632 that electrocautery current travels along within surgical field 626 to prevent burning of tissue at the surface of the ground electrode 624 and to reduce any arcing, shorting, or burning of tissue that may be caused by providing a conductive path length that is too short. This can be especially important when performing electrocautery with surgical instrument 600 in an undeployed configuration, as shown, where the distal ends of pressure lumen 620 and evacuation lumen 618 are in very close proximity.

Upon operation of electrocautery, current will flow from electrode 622 and through the target tissue and electrically conductive fluid in surgical field 626 to a conducting surface at ground potential, for example the uninsulated surface 624 of evacuation lumen 618 and sheath 612, which is in electrical communication with lumen 618. Positive electrode 622 and ground electrode surface 624 of evacuation lumen 618 within the surgical field are preferably sized, based on the power rating of the power supply supplying power to the positive electrode, to focus electrical energy at the positive electrode and disperse the energy at the ground electrode. In typical prior art electrocautery instruments for performing bipolar electrocautery, the positive and ground electrodes are of essentially equal size. In such prior art instruments, essentially all of the tissue located between the electrodes gets desiccated by electric current during operation of the instrument. In the inventive configuration, it is preferred that the surface area of the ground electrode surfaces that are submerged in conductive liquid within surgical field 626 exceed the surface area of positive electrode 622 by at least a factor of 2, more preferably by at least a factor of 5, and most preferably by at least about a factor of 10. In all cases, the ground electrode should be sized, with respect to the size of the positive electrode and the power supplied to the positive electrode, so that it is large enough to prevent boiling of any of the liquid contained within surgical field 626, when performing electrocautery with the instrument. For example, in the embodiment illustrated, positive electrode 622 comprises a positive electrode surface area of about 0.2 cm^2, while the insulated surface 630 of the distal end of evacuation lumen 618 comprises the distal-most about 0.20 inch of the lumen, providing a conductive surface 624 of evacuation lumen 618 in

In the illustrated embodiment, the pressure and evacuation lumen are constructed from a conductive material, such as stainless steel, that has a relatively low resistance to electrical current flow. The insulating coating provided on the outer surfaces of the lumen as described can comprise any insulating coating known to those of ordinary skill in the art. In one preferred embodiment, the coating comprises a polymeric coating formed on the surfaces of the lumen as shown using commercially available shrink-wrap tubing, for example polyvinylidene fluoride (PVDF) shrink wrap tubing. In another embodiment, the insulating coating comprises a polymeric coating (e.g. PVDF) formed on the outer surface by a variety of well known coating methods, for example spray coating, brush coating. dip coating, etc. with a variety of commercially available polymer layer forming solutions as known in the art. In one preferred embodiment, the insulating layer formed on pressure lumen 620 comprises a polymeric coating formed on the surface of the lumen using PVDF shrink-wrap tubing, while the insulating layer formed on the distal end of evacuation lumen 620 is formed by spray coating with a PVDF layer forming solution.

The thickness of the electrical insulating layer should be chosen to prevent electrical conduction through the layer during operation at maximum expected operating potentials of the instrument. The thickness will depend upon the well known electrical properties of the particular type of commercially available electrical insulation chosen and can be readily determined by those of ordinary skill in the art. In one embodiment, PVDF shrink-wrap tubing having a thickness of between about 0.004 inch and about 0.006 inch is used as the electrical coating for an instrument having a 1,500 volt peak-to-peak rating.

The distal end of surgical instrument 600 is shown in greater detail in FIGs. 14B and 14C. FIGs. 14B and 14C also show sheath 612 and rotatably mounted collar 610 in greater detail. Distal end 608 of surgical instrument 600 is shown in FIG. 14B in the undeployed position and in FIG. 14C in the deployed position. In the undeployed position, distal end 608 has a cross-sectional dimension, length, and angular orientation θ with respect to the longitudinal axis of the sheath 612 and the longitudinal axis of the body 602 of instrument 600, which are selected to facilitate insertion of distal end 608 into a confined surgical operating space, for example a joint capsule, for a particular surgical procedure. For example, for arthroscopy, at least one cross-sectional dimension of distal end 608, when in the undeployed configuration, should be no greater than about 2.8 mm, the length of distal end 608 is preferably between 10 and 15 mm, and angle θ is preferably about 15 degrees. Pressure lumen 620 is fixably mounted within body 602, so that it is essentially immobile

FIG 14D also illustrates one embodiment for providing electrical connections between pressure lumen 620 and positive jack 640 and between evacuation lumen 618 and ground jack 644 within body 602. Positive jack 640 is electrically connected to pressure lumen 620 via a wire or other electrical connector 668, and ground jack 644 is electrically connected to evacuation lumen 618 via a wire or other electrical connector 669. Wire/connector 668 is, in turn, crimped to, soldered to, or otherwise connected in electrical contact (by any suitable means known to those of ordinary skill in the art) to an electrically conductive surface of pressure lumen 620 at point 670; likewise, wire/connector 669 is, in turn, crimped to, soldered to, or otherwise connected in electrical contact to an electrically conductive surface of pressure lumen 618 at point 672. Either or both of high pressure conduit 662 and high pressure connector 667 should be constructed from, or coated with, an electrically insulating material (e.g. a plastic material) to prevent exposure of an operator to electrical shock via contact with the region 674 of the high pressure conduit extending outside of body 602.

The actuating mechanism by which actuating element 606 causes rotation of rotatably mounted collar 610 and sheath 612, in order to deploy distal end 608 of instrument 600, is shown more clearly in FIGs. 14E and 14F. Referring to FIG. 14E, a cut away view of actuating element 606 is shown. Actuating element 606 can be generally cylindrical in shape and includes two apertures 676 and 678. Aperture 676 is located on the proximal surface of actuating element 606 and allows actuating element 606 to accommodate body 602 of instrument 600. Aperture 678 is located on the distal surface of actuating element 606 and has a circumference that is nearly equal or slightly greater than the outer circumference of rotatably mounted collar 610, thus allowing rotatably mounted collar 610 to pass through, and rotate within, aperture 678. Bearing flange 654 of rotatably mounted collar 610 is rotatably mounted within bearing slots 680 of body 602. Shown in FIG. 14F, actuating element 606 includes a pin 682 mounted within aperture 678. As shown more clearly in FIG. 14E, when assembled, pin 682 fits within slot 650 of rotatably mounted collar 610 so that as an operator slides actuating element 606 in the direction of arrow 684, pin 682 slides forward in slot 650 causing rotation of rotatably mounted collar 610 in the direction shown by arrow 686, thus causing deployment of the distal end of instrument 600.

FIG. 15 illustrates a preferred method, according to the invention, for forming the nozzle shown above in FIGs. 14A and 14B for deployable liquid jet instruments having adjustable liquid jet cutting path lengths. Such instruments and nozzles are described in greater detail in commonly owned U.S. Patent Application Serial No. 09/313,679. Step 1 of

efficiency for forming a liquid jet as a high pressure liquid streams through the nozzle. The efficiency of forming the liquid jet is improved over nozzle designs comprising, for example, a hole bored in the side of a lumen, due to the fact that necked region 702 provides a smooth tapering flow path for the liquid flowing into nozzle region 704, thus reducing turbulence, recirculating flow patterns, and friction at the jet nozzle inlet. This effect is known in the fluid mechanical arts as the "vena contracta" effect and can improve fluid flow efficiencies through nozzles by as much as 30%.

FIGs. 16A and 16B illustrate a surgical instrument 1000 including integrated bipolar electrocautery that is similar in configuration with surgical instrument 100 previously shown in FIG. 1 above. The integrated electrocautery configuration for instrument 1000 is similar to that described above for instrument 600 of FIGs. 14A-14F, except that for instrument 1000, which includes a grinding burr 122 located at the distal end 116 and including a liquid jet-driven rotatable rotor and rotatable shaft for rotating the grinding burr, it is preferable to utilize the liquid cutting jet evacuation lumen 120 as the lumen providing positive electrode 1002 at the distal end of the surgical instrument. It is preferred to utilize evacuation lumen 120 as the positive electrode in surgical instrument 1000 because evacuation lumen 120 is connected within body 104 of the instrument to evacuation conduit connecting block 176 which, in turn, is connected to evacuation conduits 178, which extend from the proximal end of the surgical instrument. Evacuation conduit connecting block 176 and conduits 178 are constructed of electrically non-conductive polymeric materials that do not conduct electricity from evacuation lumen 120 to any surface of the instrument in contact with the user during operation. Conversely, cutting jet pressure lumen 118, which is connected within body 104 in electrical communication with ground terminal 1004 of external power supply 1006, is connected via high pressure connector 190 to liquid flow directing valve 180. The high pressure connector and liquid flow directing valve, as well as high pressure tubing coupler 186 and, in some embodiments, knobs 197, may be constructed of conducting materials and could come in contact with an operator of the device during operation. Thus, it is important that such surfaces be maintained at ground potential during operation of the electrocautery electrodes of the device.

External power supply 1006 preferably comprises a radio frequency generator as previously described in the context of FIG. 14A above. Positive terminal 1008 of power supply 1006 is in electrical communication with evacuation lumen 120 via electrical connector 1010, jack 1012, and electrical connector 1014 within body 104 of the instrument.

terminal of the power supply, for example the uninsulated surface 1031 of pressure lumen 118, as well as other conducting surfaces within surgical field 1032 that are in electrical communication with the pressure lumen, such as grinding burr 122, burr tip support 136, sheath 132, etc. Instrument 1000 could, in alternative embodiments, be connected to a power supply providing monopolar output for performing electrocautery, as was previously described for instrument 600. Also, in other embodiments, because the distal ends of evacuation lumen 120 and pressure lumen 118 are maintained at an essentially constant separation distance during operation of the device, unlike deployable device 600 shown previously in FIGs. 14A-14F, insulated tip 1030 of pressure lumen 118 can be eliminated (i.e., the entirety of the external surface of pressure lumen 118 may be electrically conductive) without unduly affecting performance of electrocautery with the instrument.

The inventive surgical instruments described herein enable the performance of a number of inventive surgical methods. For example, by utilizing the surgical instruments provided according to the invention, which provide both a liquid cutting jet and a rotatable component at the distal end of the instrument, surgical procedures may be performed involving both liquid jet cutting/ablating and other tasks that utilize or require rotation of a rotatable component in a surgical field, without the need for exchanging surgical instruments within the surgical field or providing multiple instruments to the surgical field. For example, the invention enables an operator of such an instrument to insert the surgical instrument into a surgical field of a patient, create a liquid cutting jet with the surgical instrument to cut or ablate a tissue or other material within the surgical field and also cause rotation of a rotatable component of the same surgical instrument within the surgical field to perform a desired surgical task, for example contacting the rotatable component with a tissue within the surgical field (e.g., bone tissue) and grinding, cutting, or ablating the tissue with a rotating surface of the rotatable component.

In some preferred embodiments, a surgical instrument provided according to the invention, for example surgical instrument 100 shown in FIG. 1, can be inserted into a surgical field endoscopically, for example via use of a trocar. In one particularly preferred embodiment, the surgical instruments are utilized within the joint capsule of a patient, for example in the knee or shoulder joint of a patient, for performing an arthroscopic surgical procedure. Utilizing surgical instrument 100, for example, further enables an operator of the instrument to perform surgical liquid jet cutting/ablating while evacuating debris and liquid created by the liquid cutting jet from the surgical field with the surgical instrument without

the joint capsule of a patient, where the surgical field is visually monitored with an endoscopic camera.

Those skilled in the art would readily appreciate that all parameters listed herein are meant to be examples and that actual parameters will depend upon the specific application for which the methods and apparatus of the present invention are used. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, the invention may be practiced otherwise than as specifically described.

What is claimed:

an evacuation lumen, including a jet-receiving opening locatable opposite the jet opening at a predetermined distance therefrom to receive the liquid cutting jet when the instrument is in operation.

8. The device as in claim 7, wherein the evacuation lumen is shaped and positionable to enable evacuation of essentially all of the liquid comprising the liquid cutting jet from the jet-receiving opening to a proximal end of the evacuation lumen without the need for an external source of suction coupled in fluid communication with the evacuation lumen.

9. The device as in claim 7, wherein at least one electrocautery electrode comprises a portion of an external surface of at least one of the pressure lumen and the evacuation lumen.

10. The device as in claim 9, wherein the surgical instrument includes at least two electrocautery electrodes operable in a bipolar mode, with each electrode being positioned at the distal end of the surgical instrument.

11. The device as in claim 10, wherein the evacuation lumen is connected in electrical communication with a positive terminal of an external power supply, and wherein the pressure lumen is connected in electrical communication with a source of ground potential.

12. The device as in claim 11, wherein the evacuation lumen has an outer surface that is electrically insulated and includes a first region near the distal end of the lumen that is not electrically insulated and that forms an electrocautery electrode and a second region located within the body of the instrument that is not electrically insulated and forms an electrical contact with the positive terminal of an external power supply.

13. A device comprising:

a surgical instrument having a distal end adapted to perform a surgical procedure on a patient and a proximal end adapted to be controllable by an operator, the instrument including:

a rotatable shaft;

a surgical component drivable by the shaft, constructed and arranged for contact with tissue in a surgical operating field;

18. The device as in claim 14, wherein the evacuation lumen is shaped and positionable to enable evacuation of essentially all of the liquid comprising the liquid cutting jet from the jet-receiving opening to a proximal end of the evacuation lumen without the need for an external source of suction coupled in fluid communication with the evacuation lumen.

19. The device as in claim 18, wherein at least one of the pressure lumen and the evacuation lumen is movable relative to the other.

20. The device as in claim 19, wherein movement of at least one of the pressure lumen and the evacuation lumen causes a change in the predetermined distance, the change in the predetermined distance causing a corresponding change in a length of the liquid cutting jet when the instrument is in operation.

21. The device as in claim 20, wherein the movement comprises a rotational movement.

22. The device as in claim 21, wherein the movement is controllable by manipulating at least a part of the proximal end of the surgical instrument.

23. A device comprising:

a surgical instrument having a distal end adapted to perform a surgical procedure on a patient and a proximal end adapted to be controllable by an operator, the instrument including:

a first lumen constructed of an electrically conducting material providing a first liquid passageway between the distal end and the proximal end of the instrument; and

a second lumen constructed of an electrically conducting material providing a second liquid passageway between the distal end and the proximal end of the instrument,

the first lumen being connectable in electrical communication with a first electrical potential, and having an external surface, at at least the distal end of the instrument, which is inserted into a surgical field of a patient when the instrument is utilized for a surgical procedure, that is coated with an essentially continuous layer of electrical insulation and includes an uninsulated region at a distal end of the first lumen, which region at a distal end of the first lumen forms a first electrocautery electrode, and

30. The device as in claim 29, wherein the total surface area of the distal end of the instrument which is inserted into a surgical field and which is maintained at ground potential exceeds the total surface area of the positive electrocautery electrode formed on the first lumen by at least a factor of about 10.

31. The device as in claim 24, wherein the positive electrocautery electrode formed on the first lumen has a total surface area of about 0.2 cm^2.

32. The device as in claim 24, wherein the total surface area of the ground electrocautery electrode formed on the second lumen is sufficient to prevent boiling of any liquid contained in the surgical field of the patient, when the instrument is in operation.

33. The device as in claim 32, wherein the ground electrocautery electrode formed on the second lumen has a total surface area of at least about 2 cm^2.

34. A method comprising:
inserting a surgical instrument into a surgical field of a patient;
creating a liquid cutting jet with the surgical instrument;
cutting or ablating a selected tissue of the patient with the liquid cutting jet;
applying an electrical signal to at least one electrode of the surgical instrument; and
cauterizing a tissue of the patient.

35. The method as in claim 34, further comprising after the creating step, the step of:
directing the liquid cutting jet towards a jet-receiving opening in an evacuation lumen of the surgical instrument.

36. The method as in claim 35, wherein at least one electrode comprises a distal surface of at least one of a pressure lumen and the evacuation lumen of the surgical instrument.

37. The method as in claim 36, wherein in the applying step, a bipolar electrical signal is applied to two electrodes of the surgical instrument.

43. The method as in claim 41, wherein the surgical field is visually monitored with an endoscopic probe.

44. The method as in claim 41, wherein in the placing step, two electrode surfaces of the surgical instrument are placed in proximity to the bleeding vessel, and wherein in the applying step, a bipolar electrical signal is applied to the electrodes to electrocauterize the bleeding vessel to stop bleeding therefrom.

45. The method as in claim 44, wherein a portion of an external surface of a pressure lumen of the surgical instrument comprises a first electrode surface and a portion of an external surface of the evacuation lumen of the surgical instrument comprises a second electrode surface.

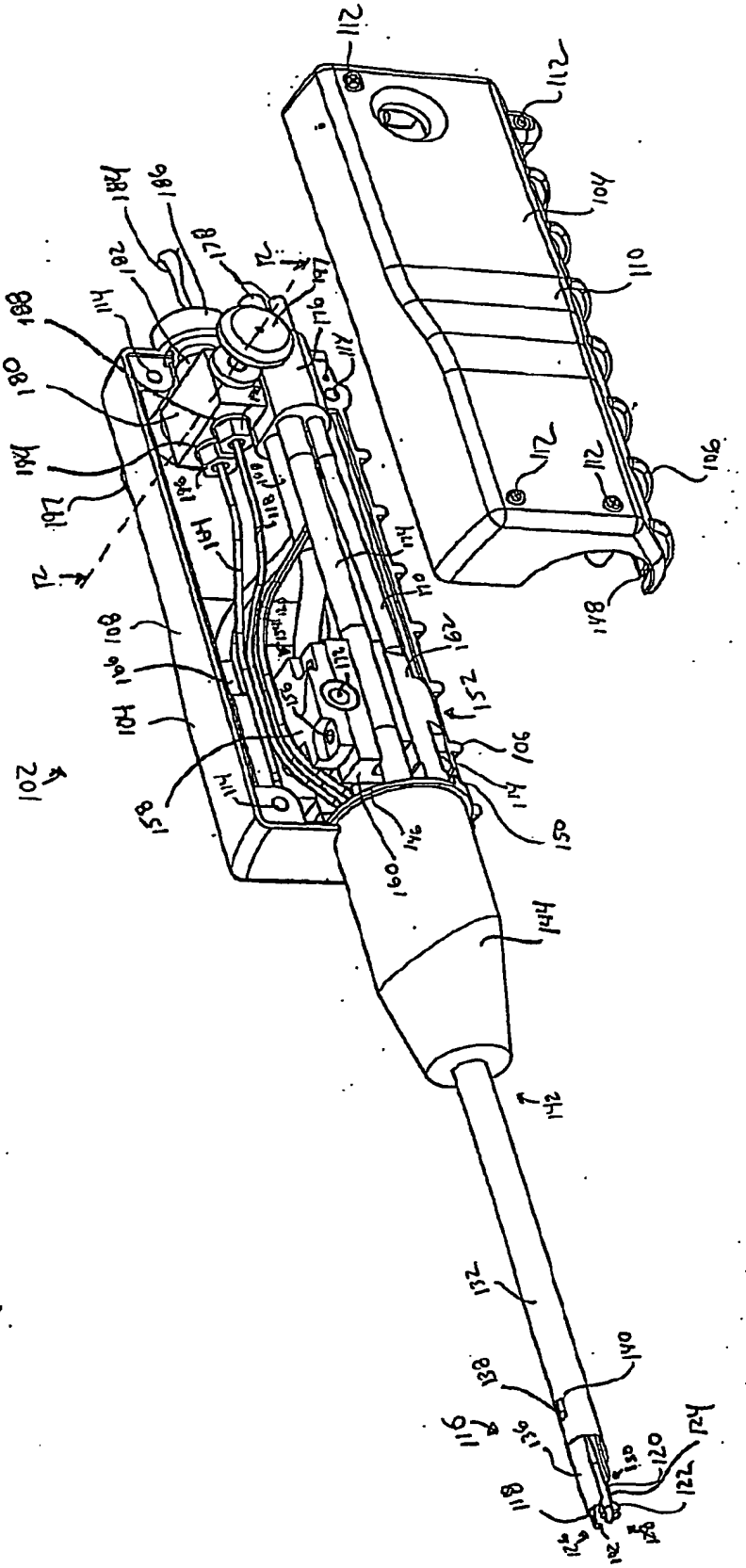

Fig 1

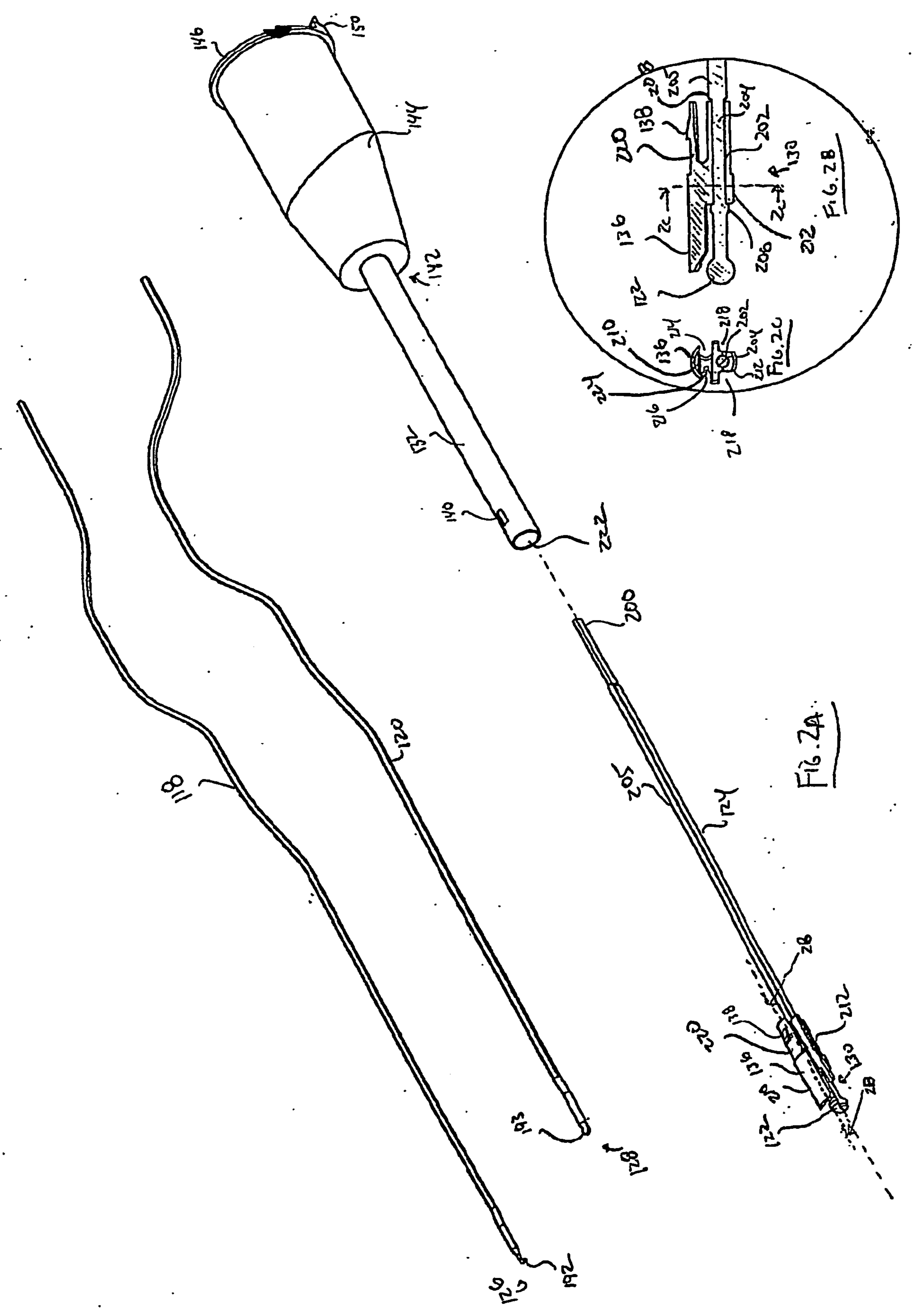

FIG. 2A

FIG. 2B

FIG. 2C

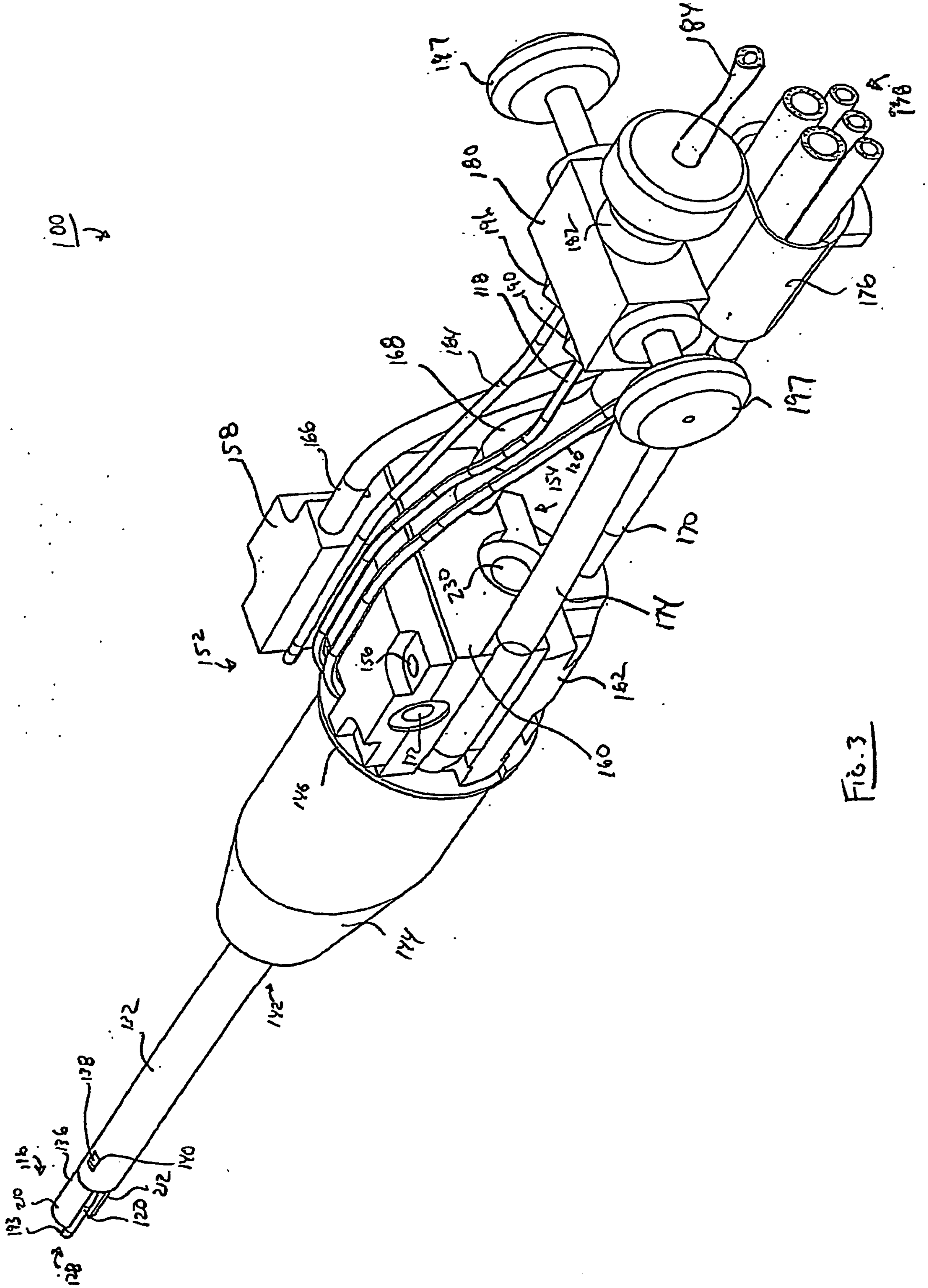
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FIG. 3

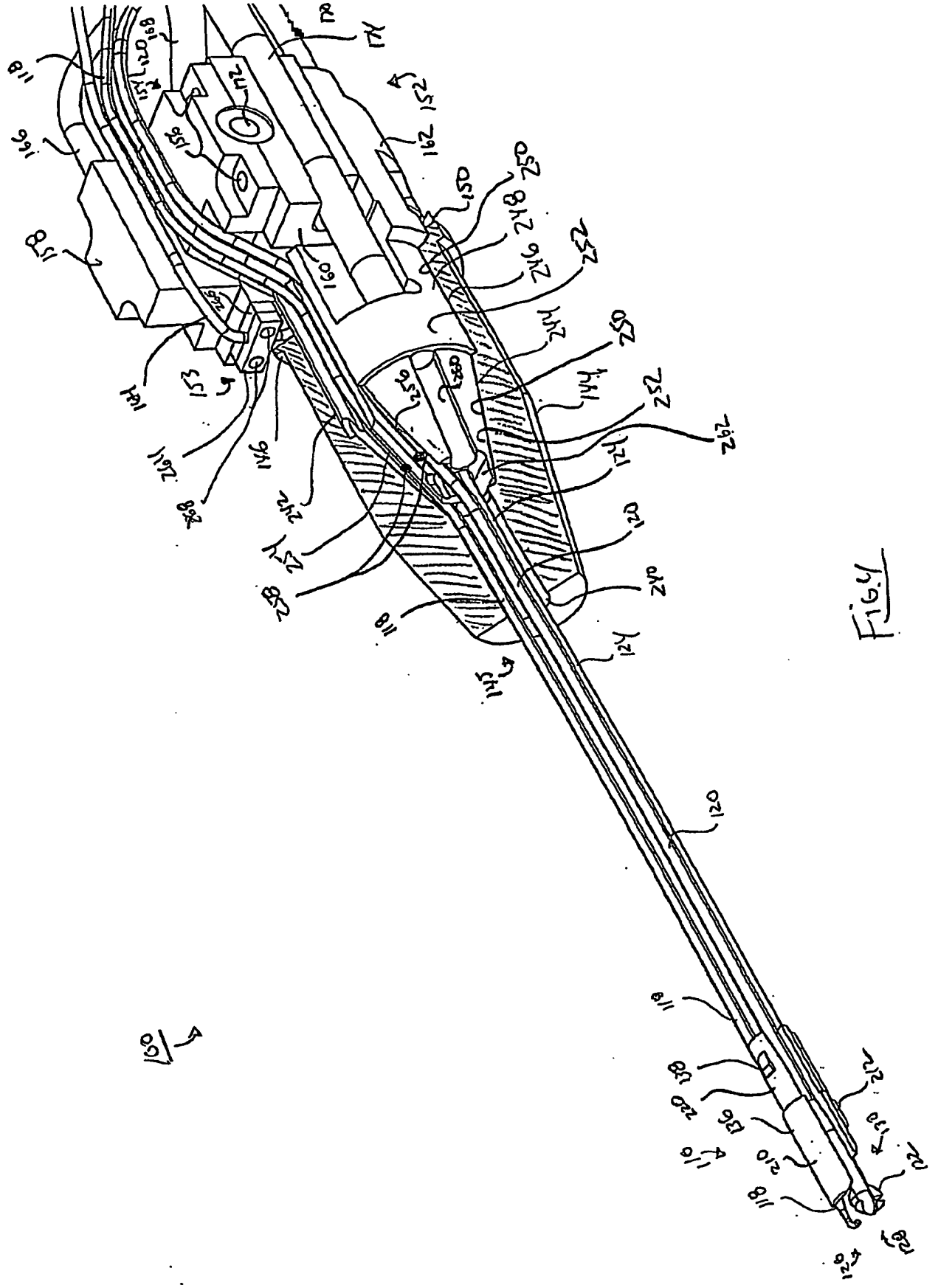

Fig. 4

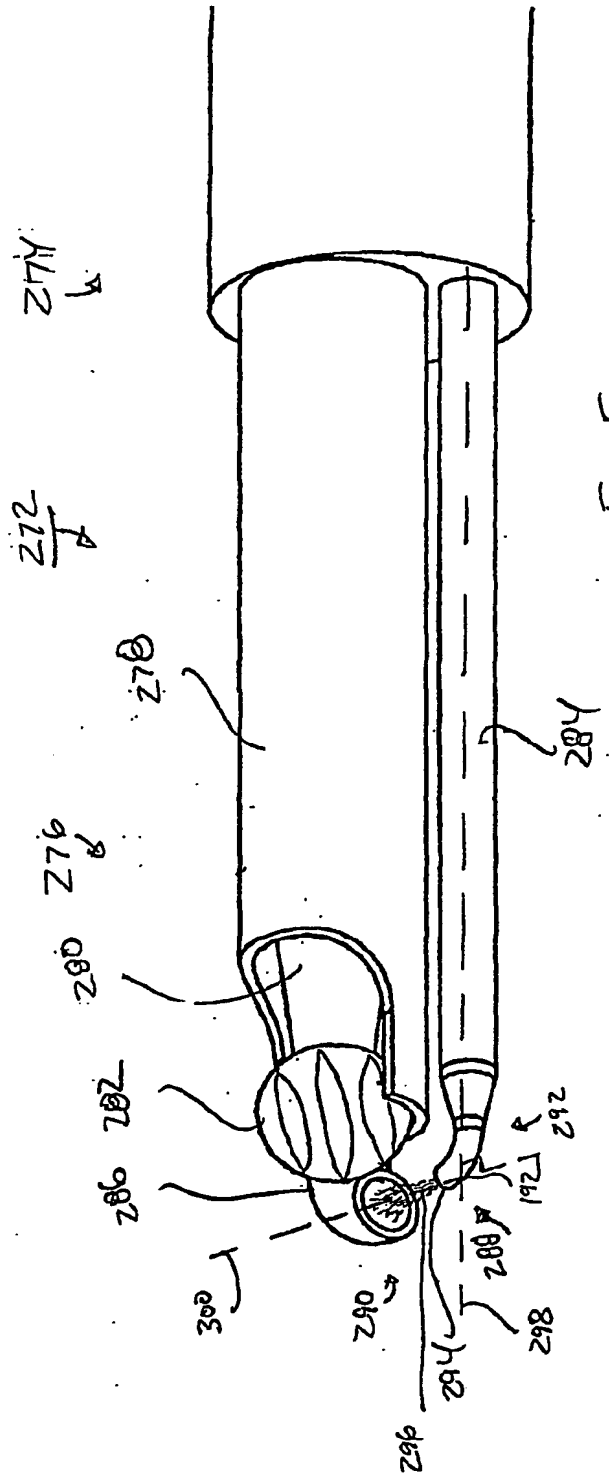
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Fig. 5A

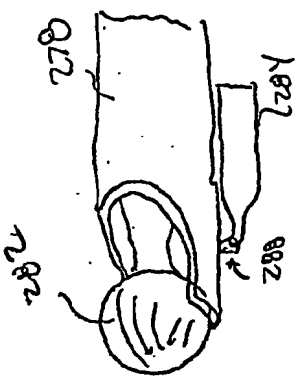
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Fig. 5B

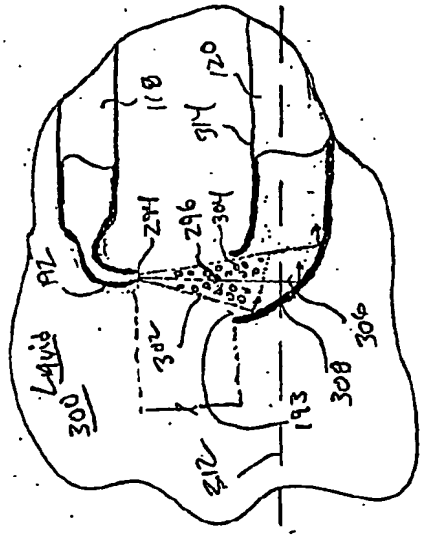


Fig 6A

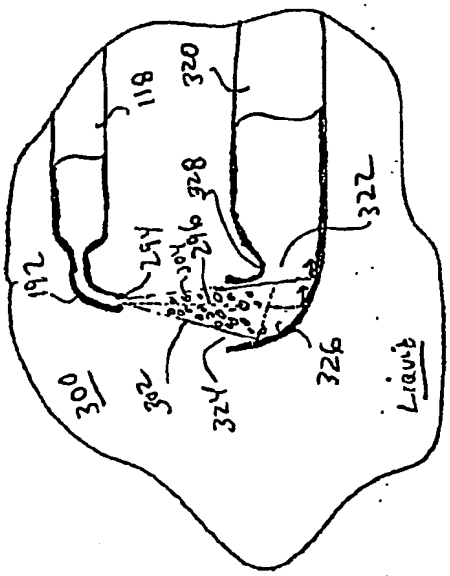
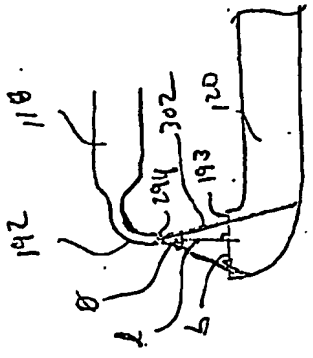


Fig 6B



b=l+a+θ

Fig 6C

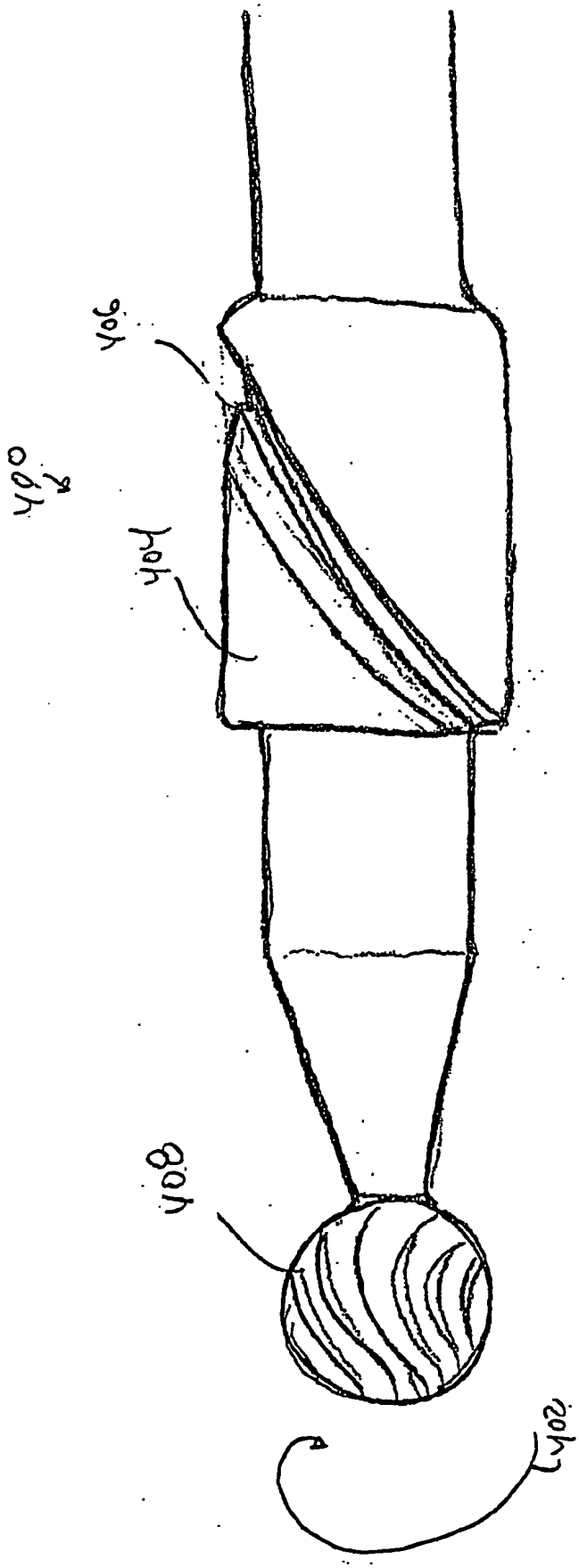


Fig. 7A

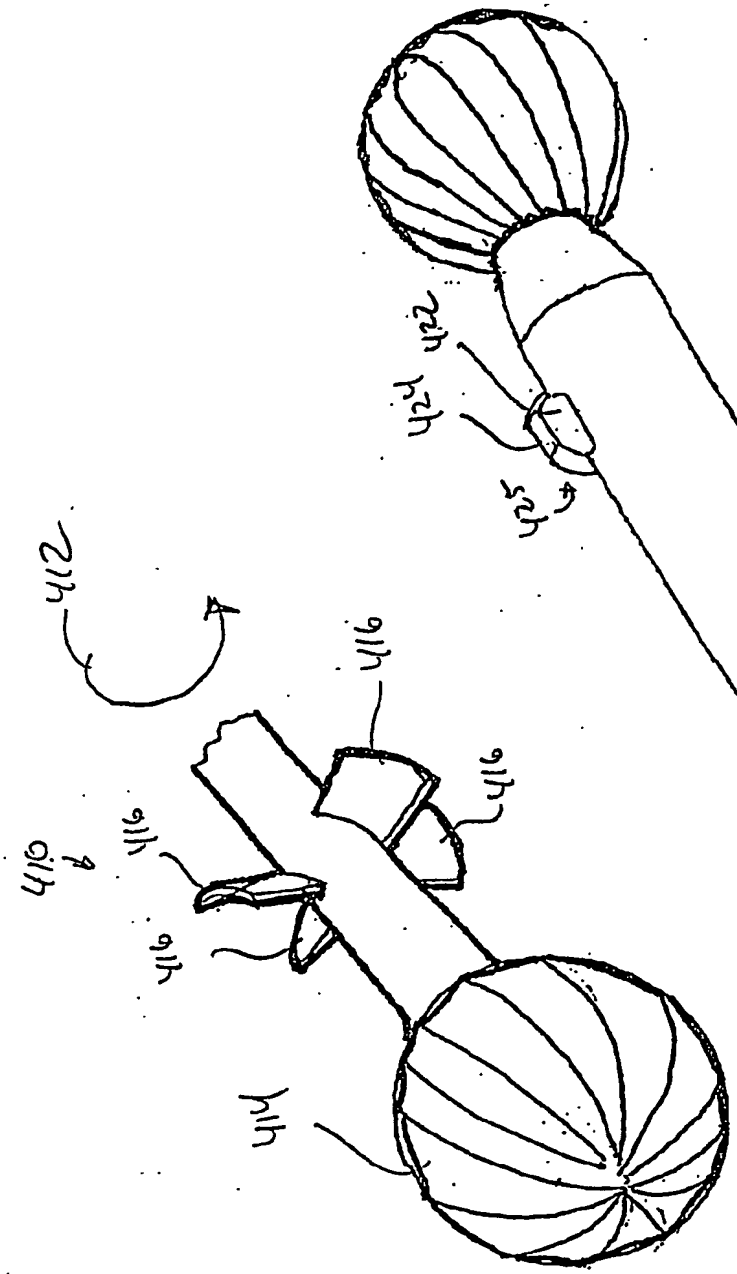


Fig. 7B

Fig. 7C

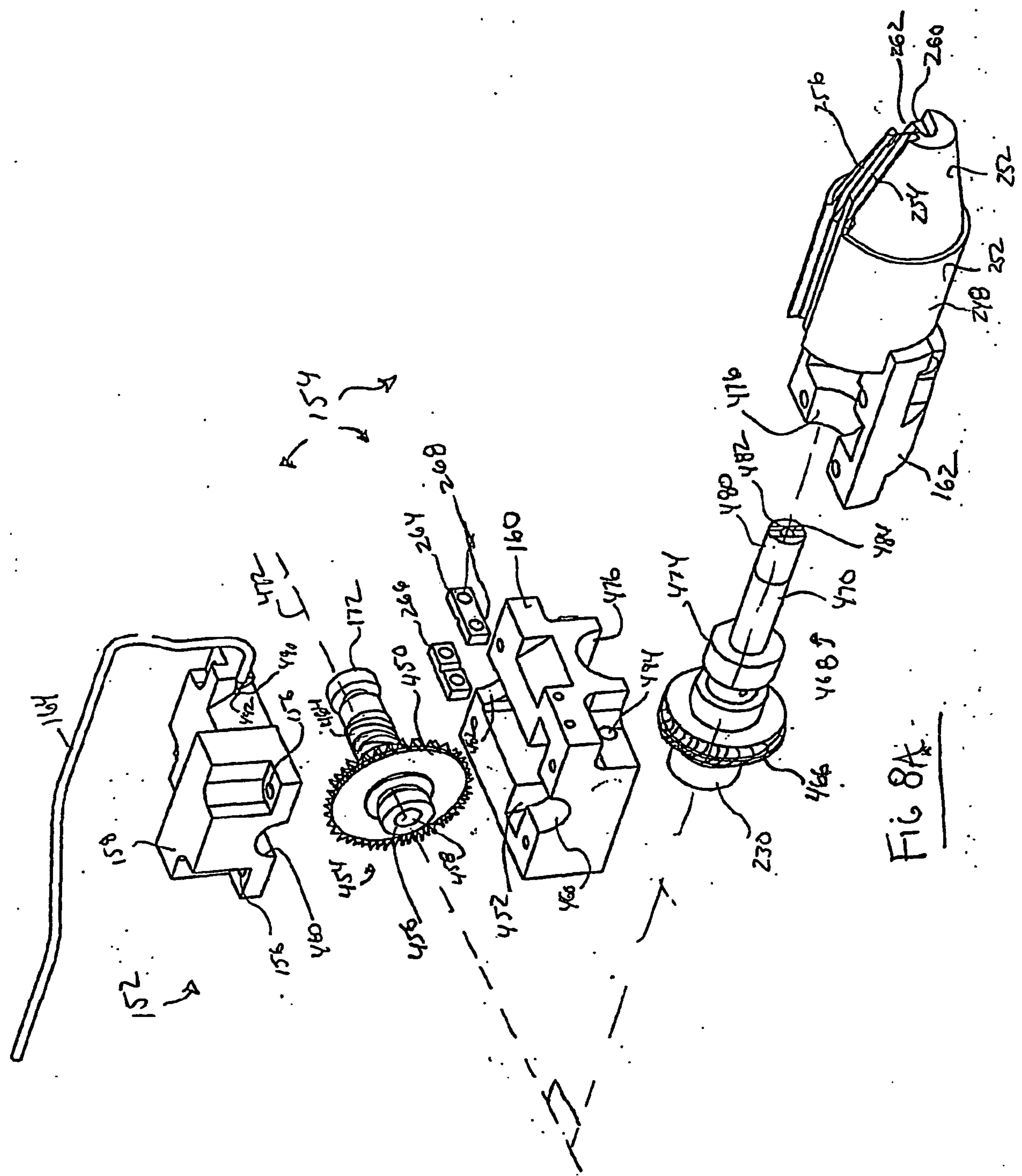

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FIG 8A

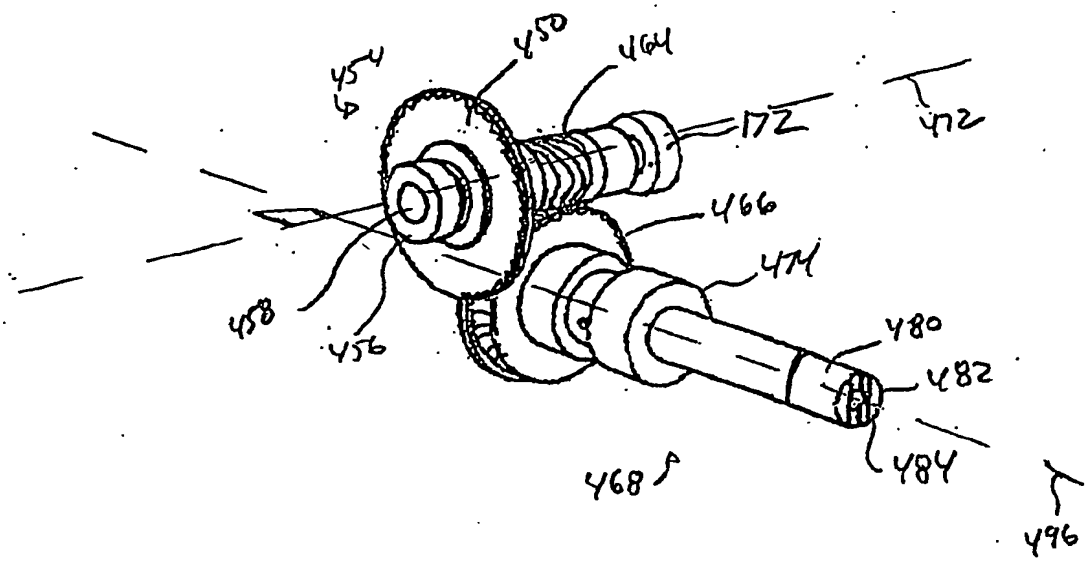


Fig 8B

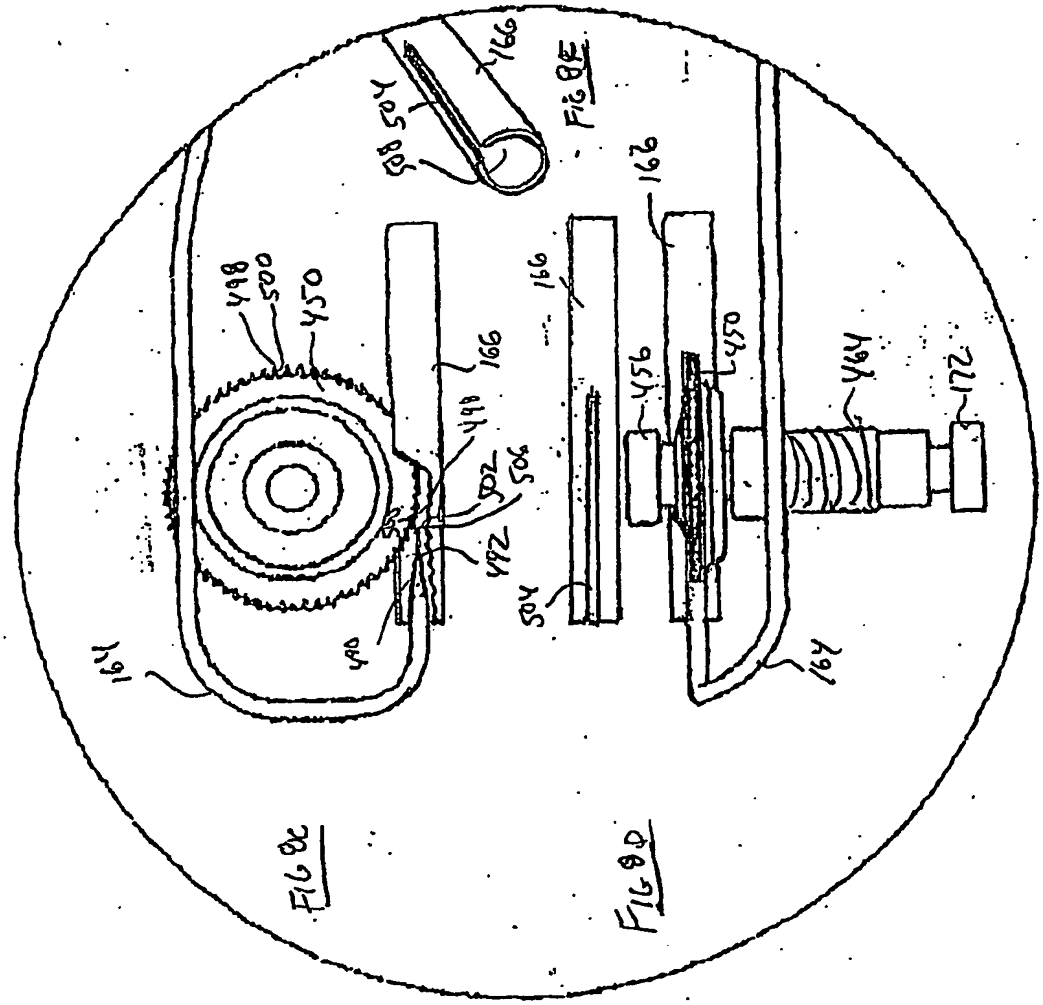
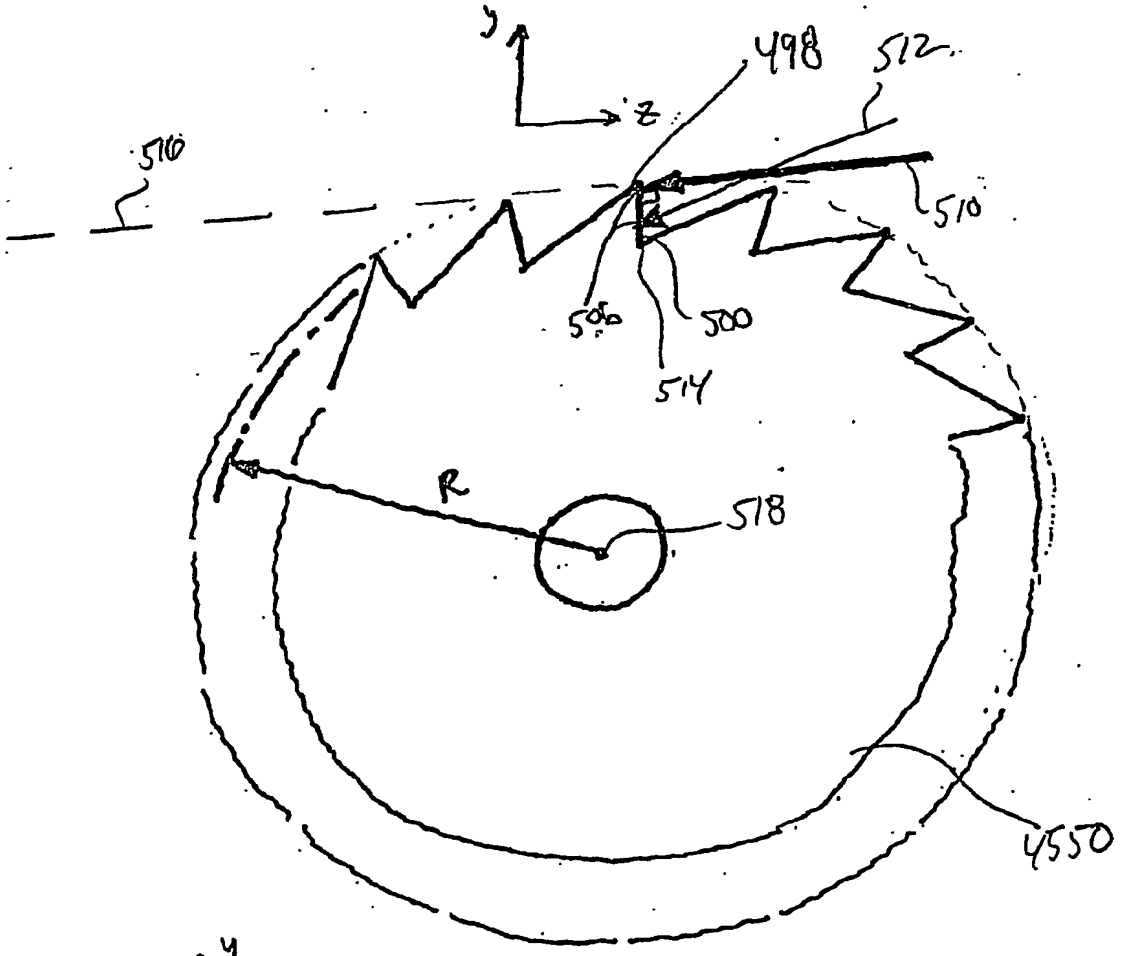


FIG 9C

FIG 9D

FIG 9E


y
z
498
512
510
510
506
500
514
R
518
4550

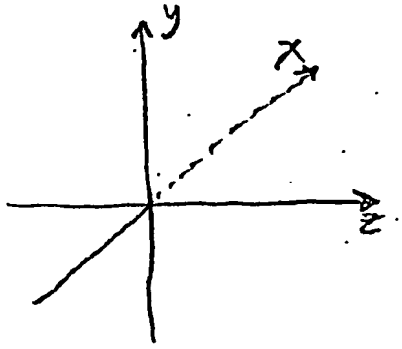

y
x
z

FIG 9A

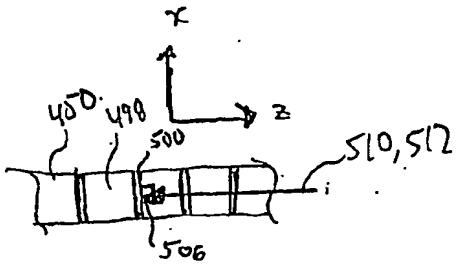

x
z
450
498
500
510,512
506

FIG. 9B

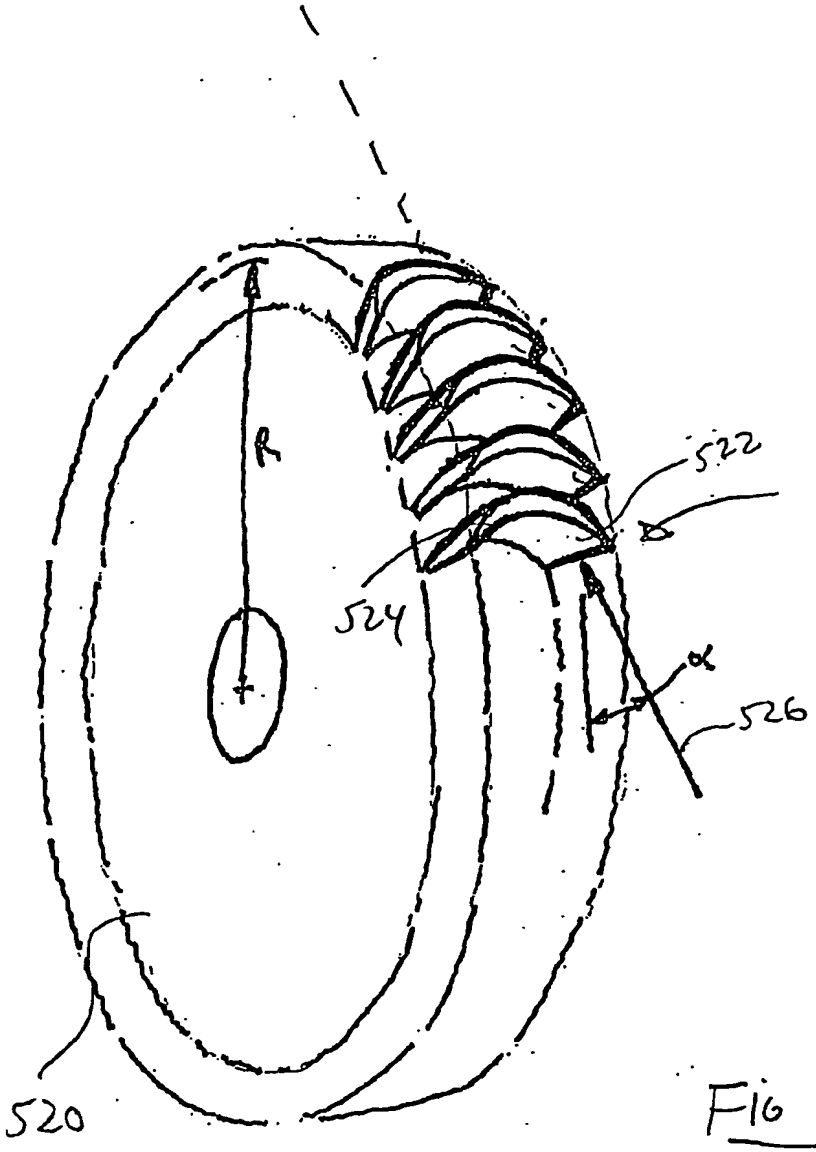


FIG 10A

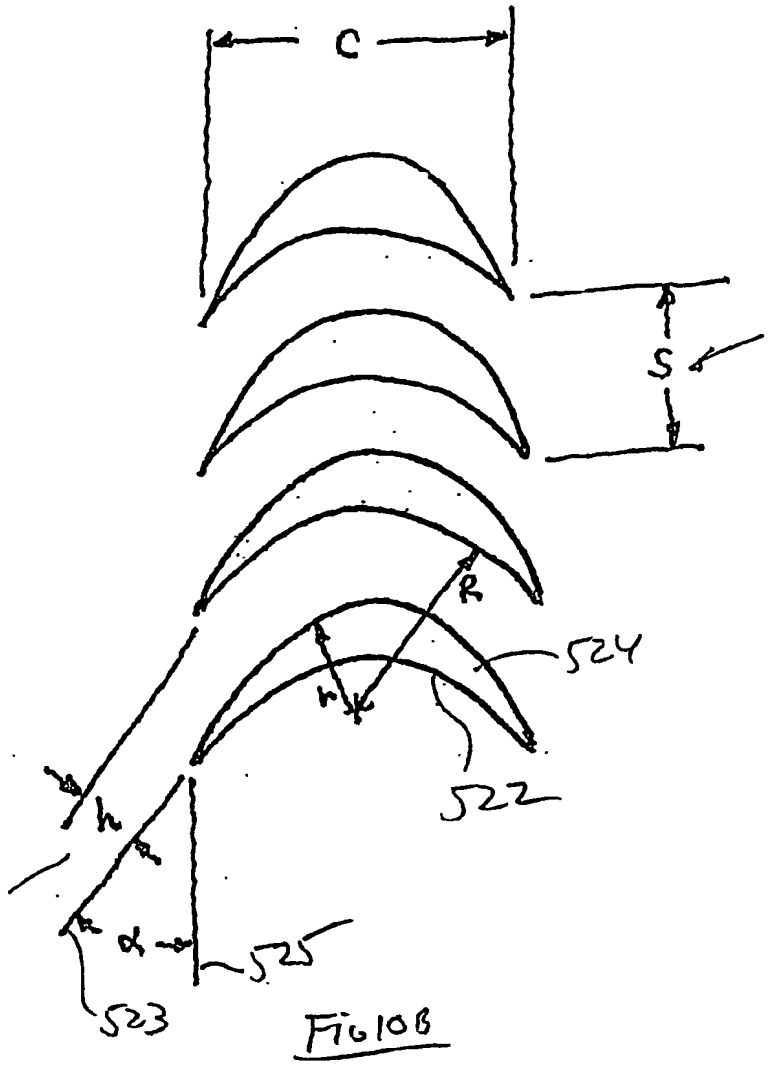


Fig 10B

Fig 11A

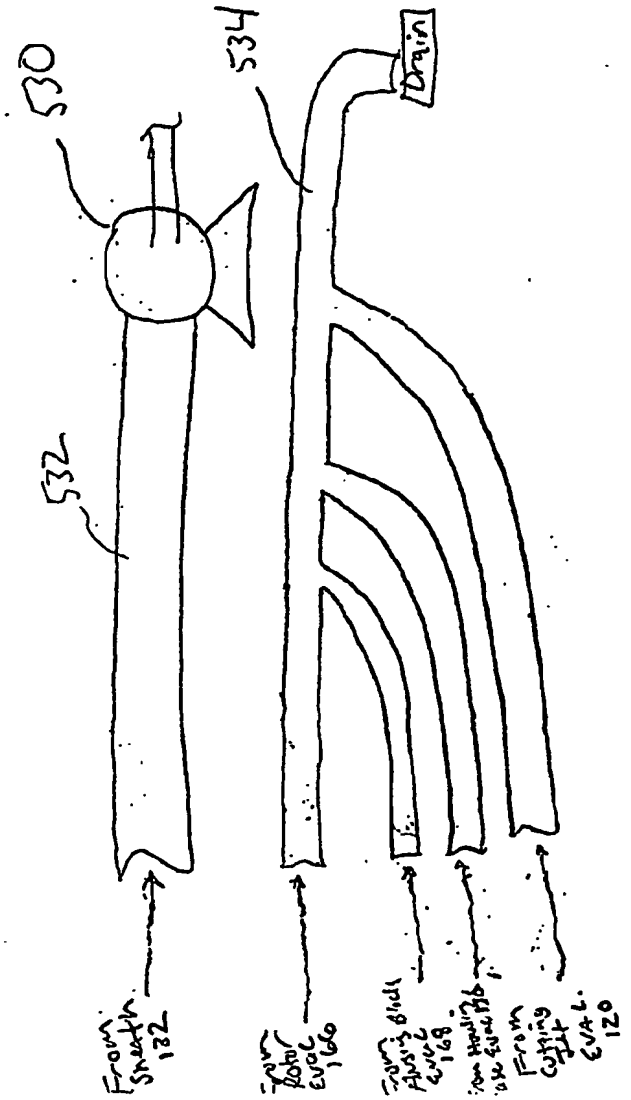
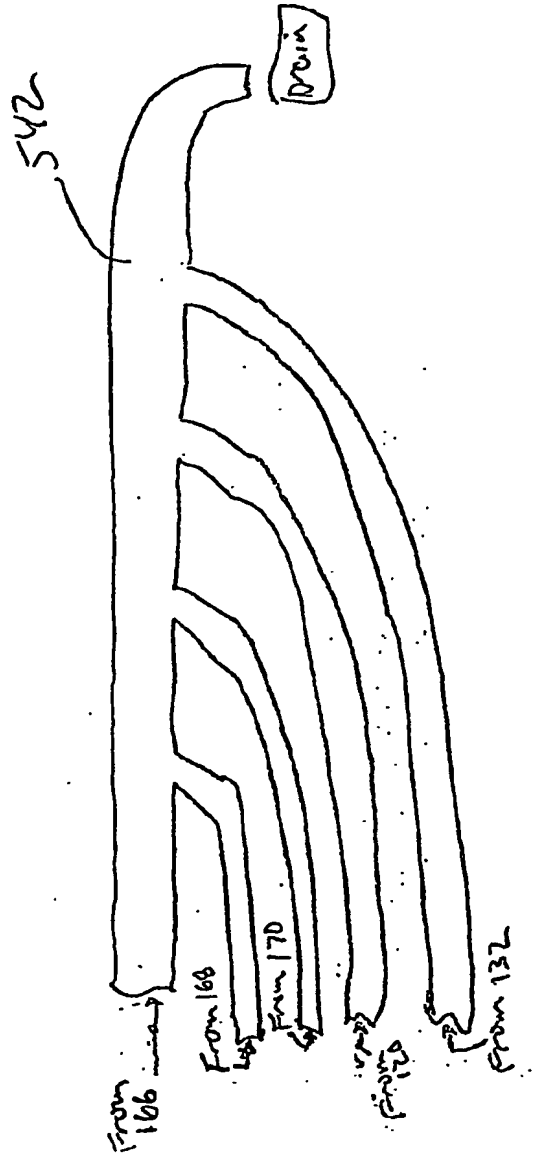


Fig 11B



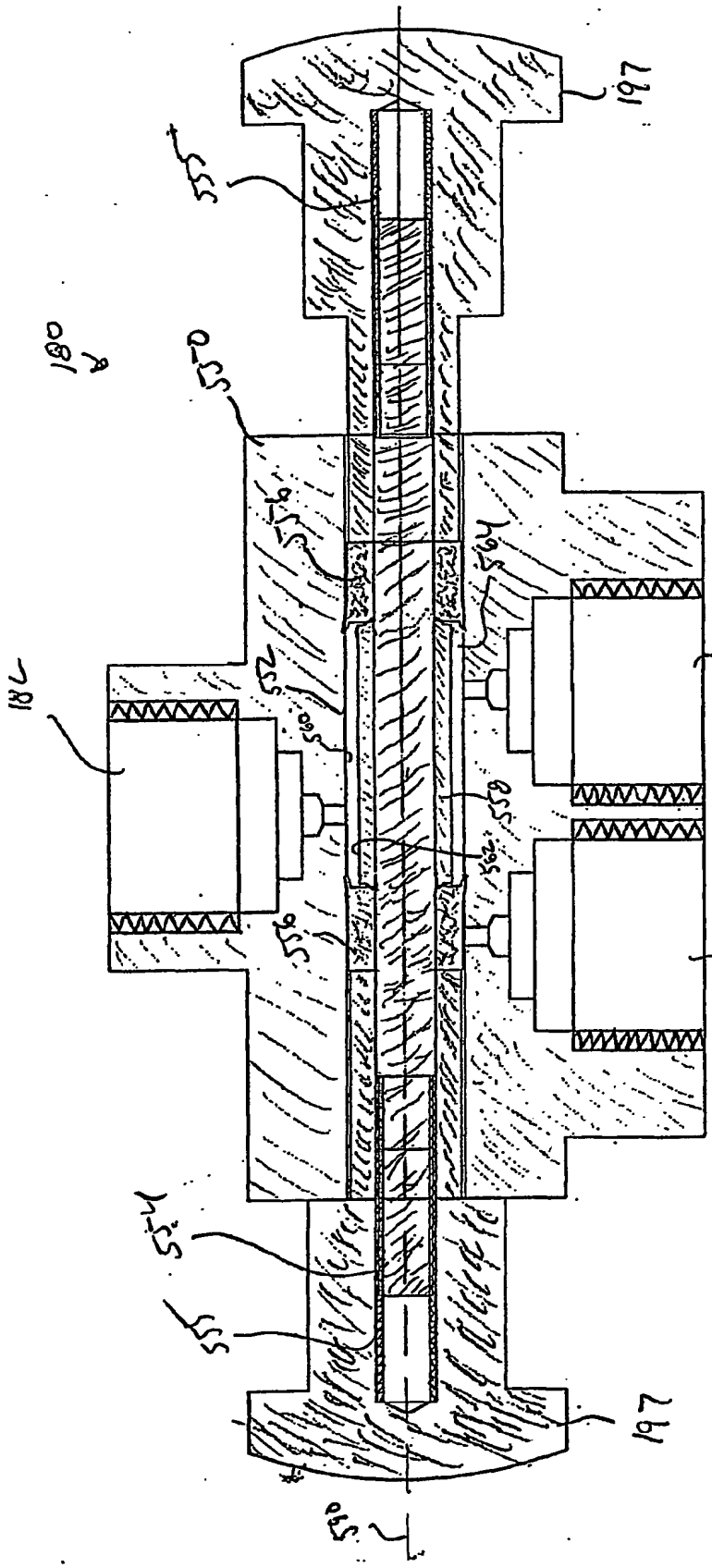


Fig 12

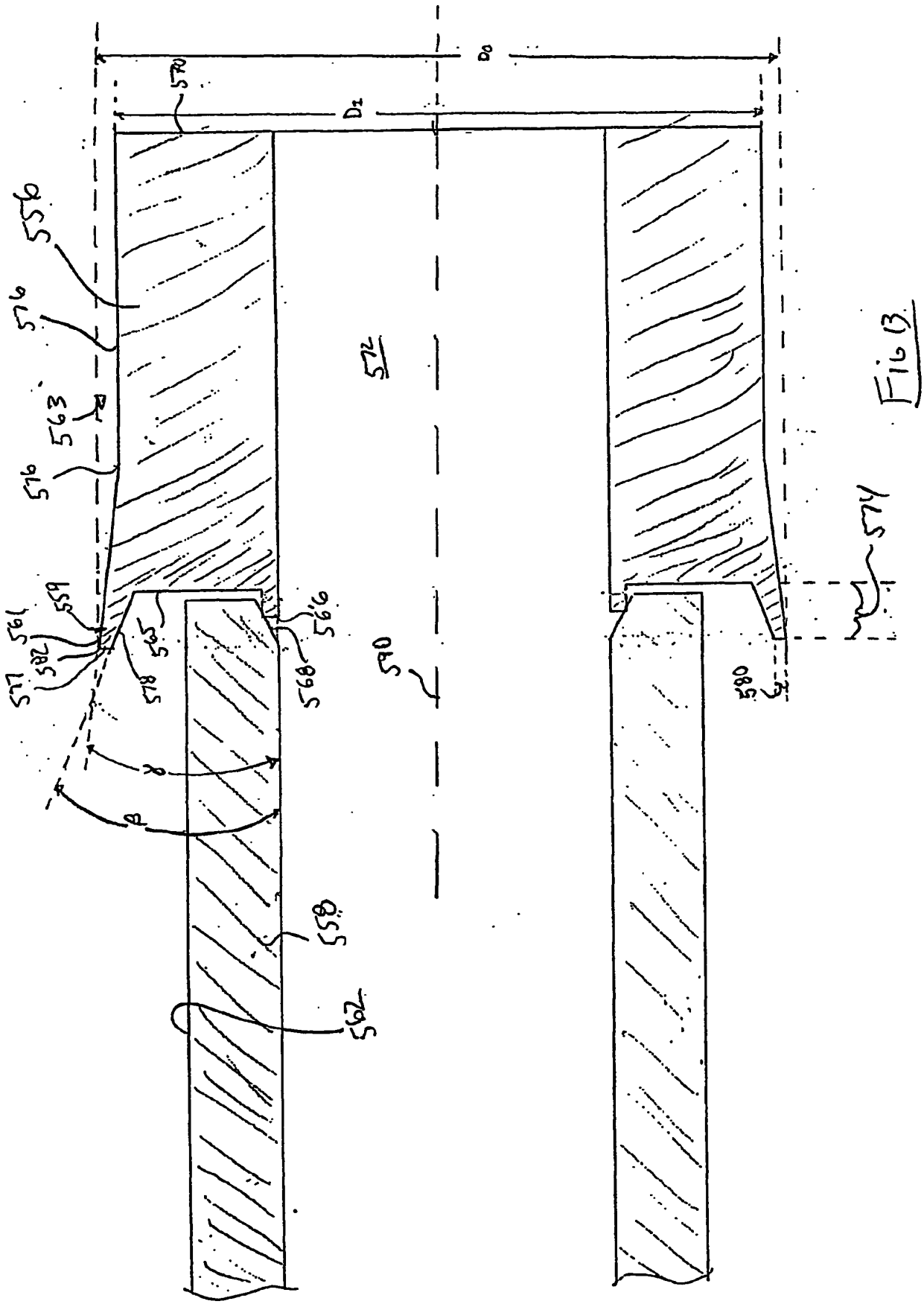

D0
D1
570
556
576
572
563
576
574
559
561
582
577
565
578
568
576
590
580
588
592
α
β

Fig 13

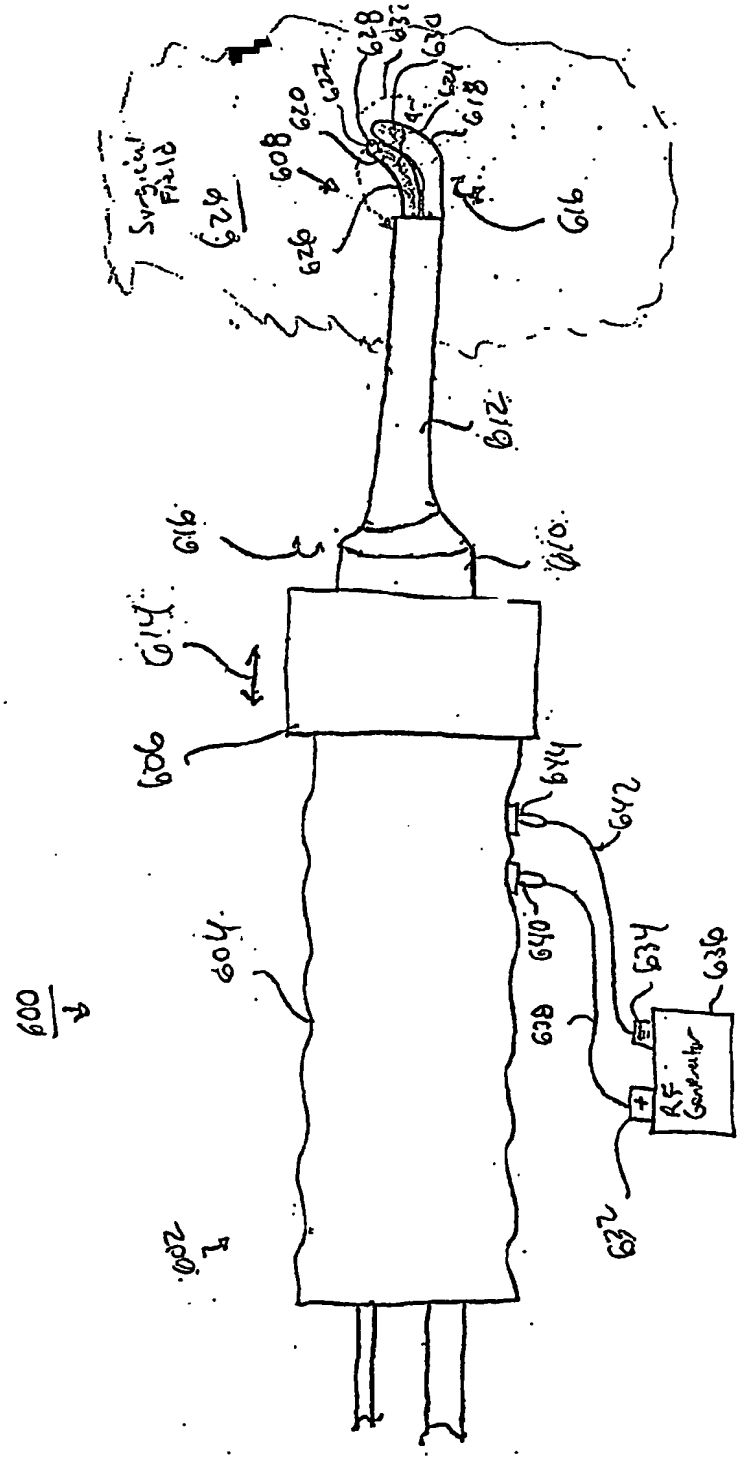

100
200
202
204
206
208
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
Surgical Field
RF Generator

Fig 14A

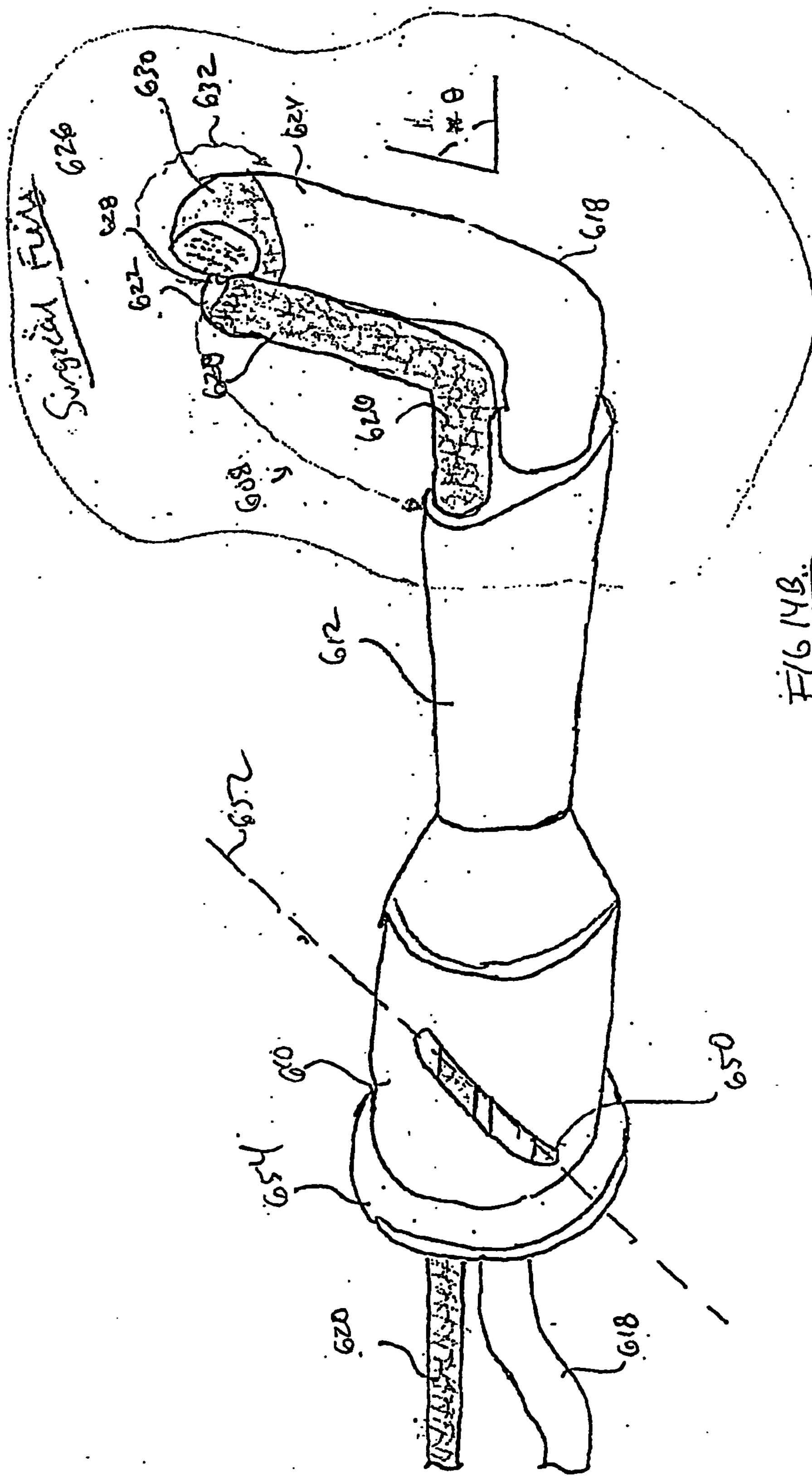

Surgical Field
626
630
632
624
628
622
618
628
626
638B
612
652
660
650
654
620
618

FIG. 14B.

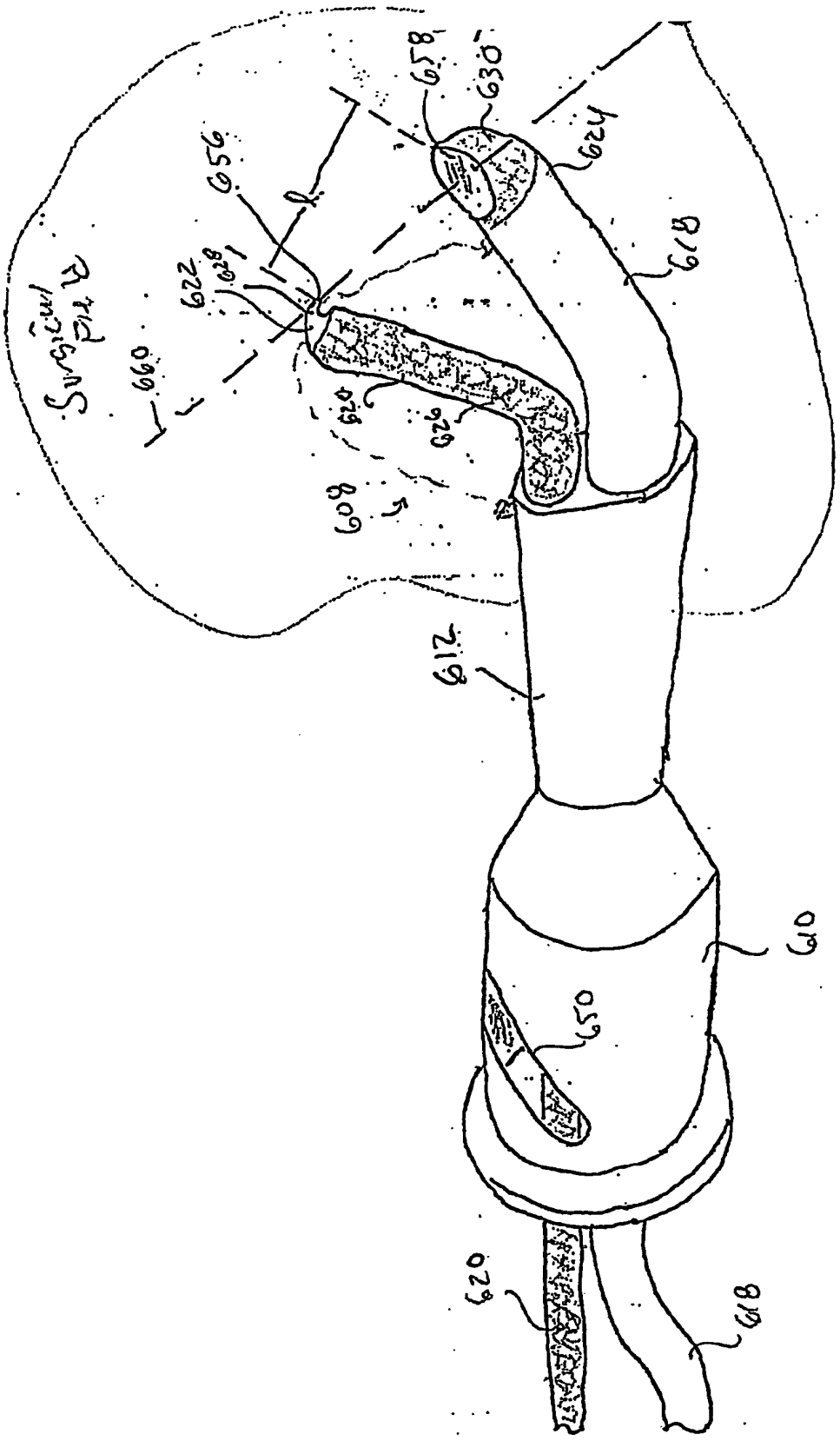

Surgical Neck
660
622
656
658
630
624
618
626
628
608
616
610
620
618

FIG. 14C

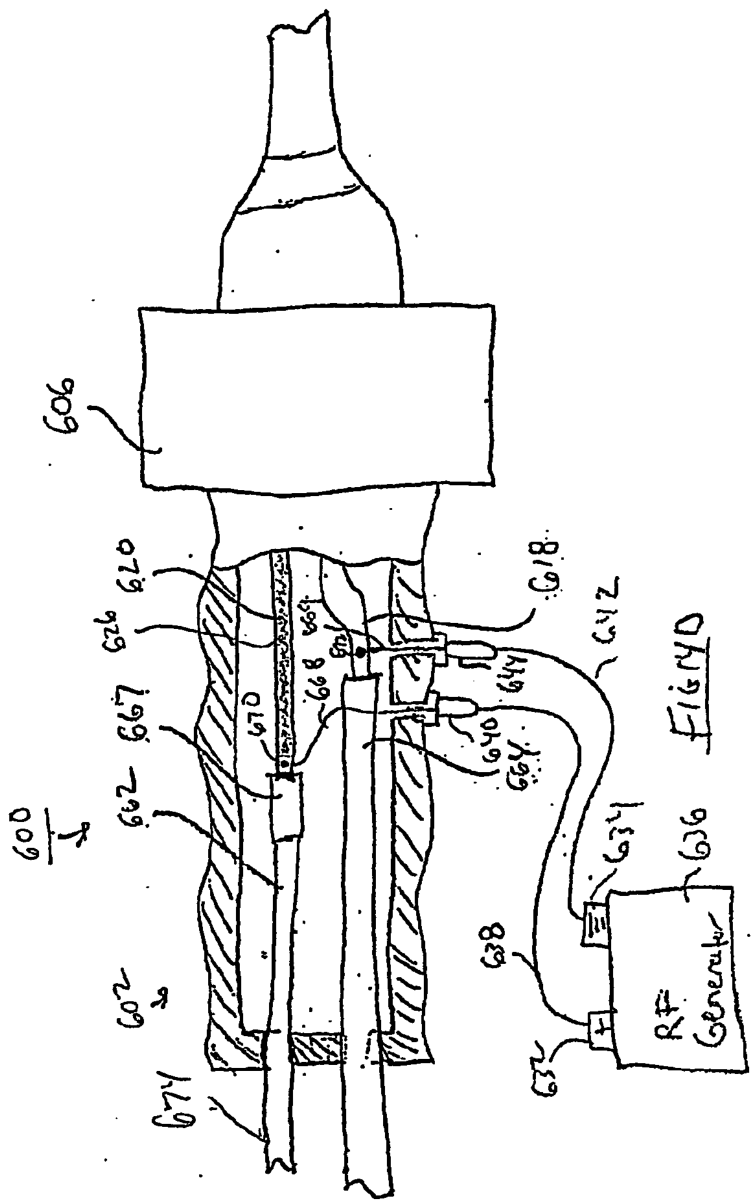

600
602
606
618
620
626
632
634
636
638
640
642
644
662
664
667
668
670
674
RF Generator

Fig 4D

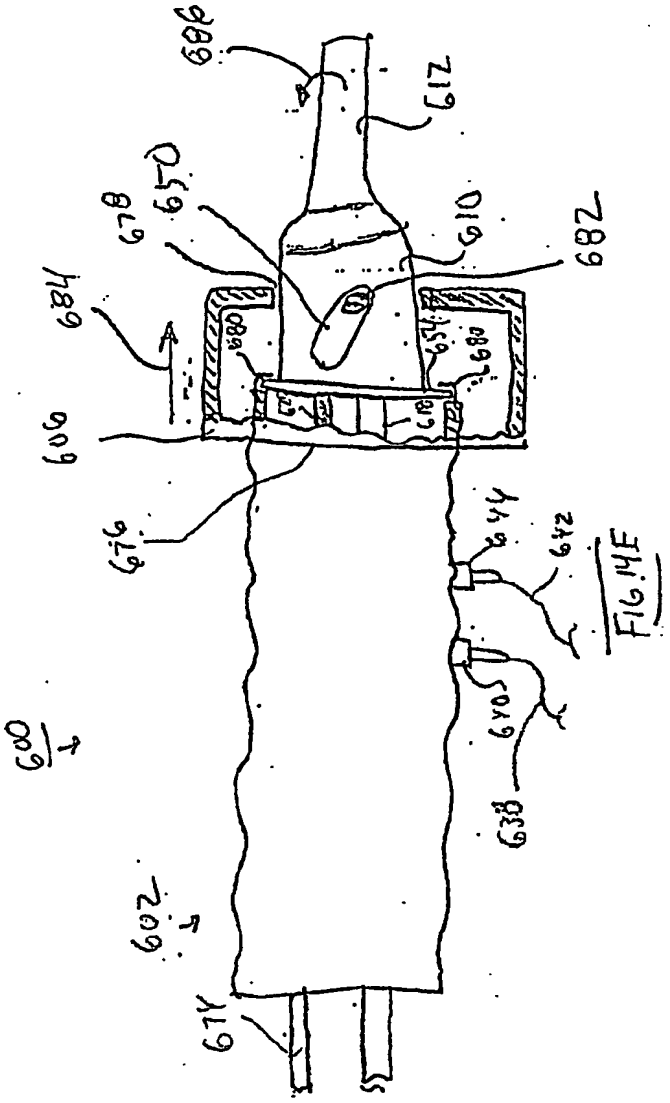


FIG 14E

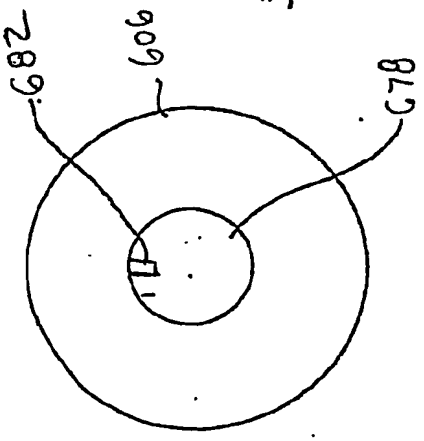


FIG 14F

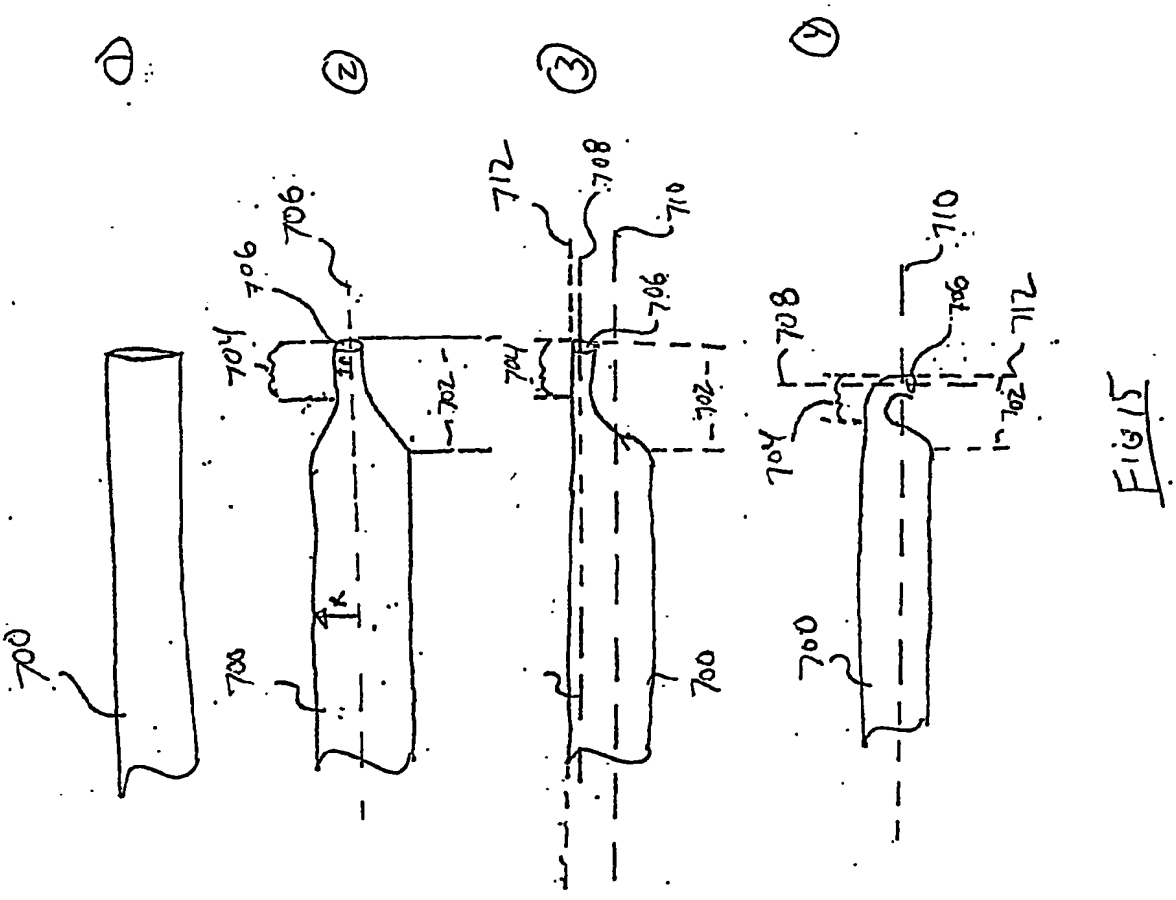


Fig 15

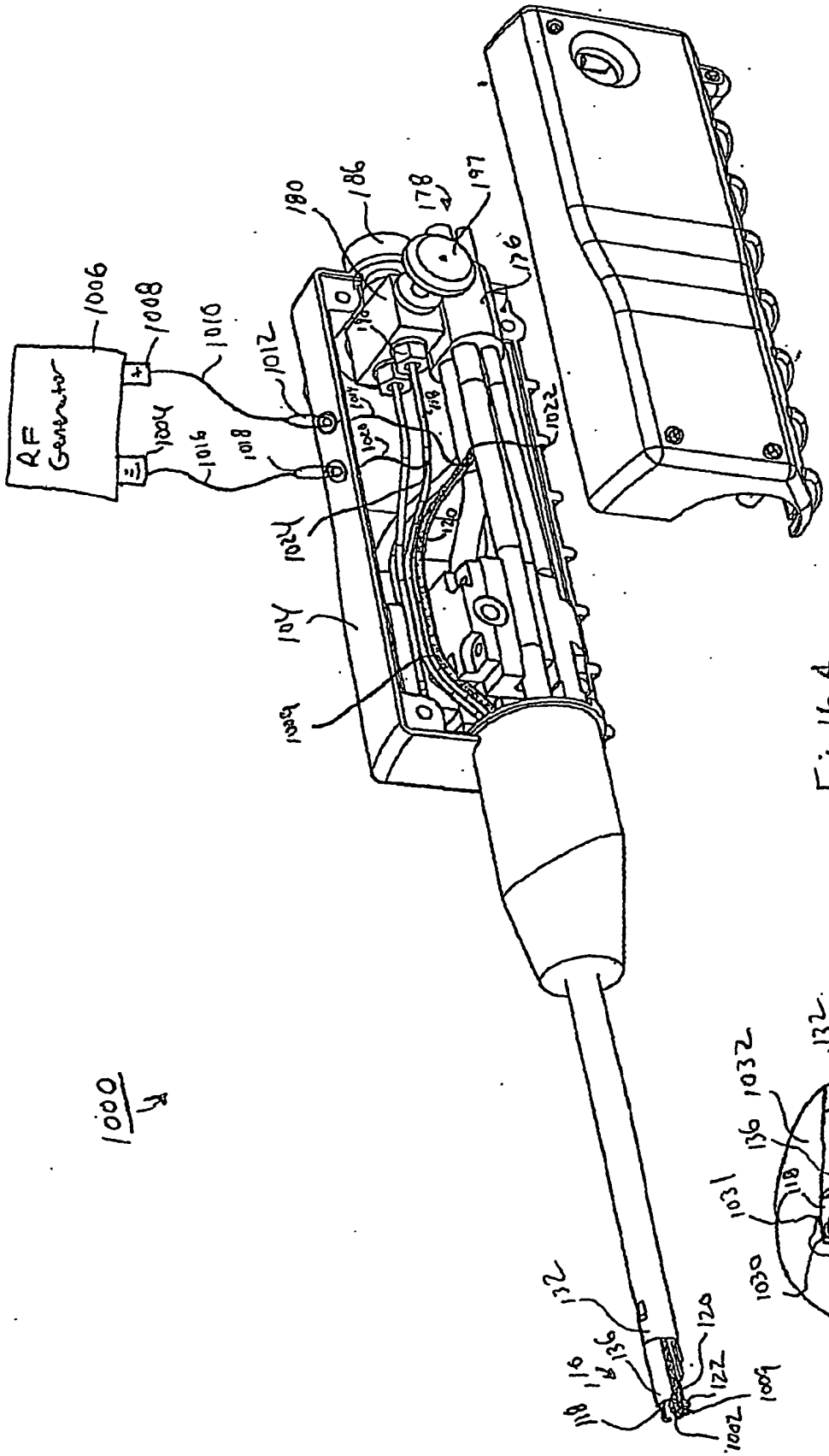


Fig 16A

Fig 16B